CLIMATE CHANGE AND AGRICULTURE

JOINT HEARING

BEFORE THE

SUBCOMMITTEE ON DEPARTMENT OPERATIONS, RESEARCH, AND FOREIGN AGRICULTURE

AND THE

SUBCOMMITTEE ON FORESTS, FAMILY FARMS, AND ENERGY

OF THE

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HOUSE OF REPRESENTATIVES

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CONTENTS

	Page
Brown, Hon. George E., Jr., a Representative in Congress from the State of California, opening statement	1
Morrison, Hon. Sid, a Representative in Congress from the State of Washington, prepared statement	4
Roberts, Hon. Pat, a Representative in Congress from the State of Kansas, opening statement	2
Volkmer, Hon. Harold L., a Representative in Congress from the State of Missouri, opening statement	3
WITNESSES	
Bentley, Orville G., Assistant Secretary, Science and Education, U.S. Department of Agriculture	5
Prepared statement	56
Crosson, Pierre, senior fellow, Resources for the Future	37
Prepared statement	105
Rosenzweig, Cynthia E., department of geography, Columbia University and NASA/Goddard Institute for Space Studies	41
Prepared statement	138
Strain, Boyd R., professor of botany, Duke University	35
Prepared statement	88
Thomas, Alan R., Acting Assistant Administrator, Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, U.S. Department of Commerce	9
Prepared statement	61
Tilford, Shelby G., Director, Earth Science and Applications Division, Office of Space Science and Applications, National Aeronautics and Space Administration	12
Prepared statement	69
Ward, Justin R., senior project associate, National Resources Defense Council	38
Prepared statement	117

CLIMATE CHANGE AND AGRICULTURE

WEDNESDAY, APRIL 19, 1989

HOUSE OF REPRESENTATIVES; SUBCOMMITTEE ON DEPARTMENT OPERATIONS, RESEARCH, AND FOREIGN AGRICULTURE AND SUBCOMMITTEE ON FORESTS, FAMILY FARMS, AND ENERGY; COMMITTEE ON AGRICULTURE,

Washington, D.C.

The subcommittees met, pursuant to notice, at 9:40 a.m., in room 1302, Longworth House Office Building, Hon. George E. Brown, Jr. (chairman of the Subcommittee on Department Operations, Research, and Foreign Agriculture) presiding.

Present from the Subcommittee on Department Operations, Research, and Foreign Agriculture: Representatives Brown, Stenholm, Olin, Volkmer, Roberts, Morrison, and Walsh.

Present from the Subcommittee on Forests, Family Farms, and Energy: Representatives, Volkmer, Olin, Stallings, Jontz, Johnson, Harris, Morrison, Schuette, and Herger.

Staff present: Daniel E. Brinza, counsel; Joseph Muldoon, assistant counsel; John E. Hogan, minority counsel; Glenda L. Temple, clerk; William A. Stiles, Jr., Rob Myers, Timothy P. De Coster, James R. Lyons, Cristy Scott, James A. Davis, John J. Aguirre, and Kraig Naasz.

OPENING STATEMENT OF HON. GEORGE E. BROWN, JR., A REPRESENTATIVE IN CONGRESS FROM THE STATE OF CALIFORNIA

Mr. BROWN. The subcommittees will come to order.

I have a brief opening statement, which will illuminate this hearing greatly, I am sure.

Today our joint subcommittees will be taking a careful look at an important issue; namely, the extent to which probable climatic change will disrupt our agricultural systems in the coming years.

We also intend to learn more about how agricultural practices might modify the rate of climatic change, and to examine the Federal programs being planned or currently in place to address the issue of global change.

It is apparent to me that scientists have long discussed the possibilities of global climate changes, both possible temperature increases and temperature decreases.

I understand that during the 1980's the scientific community has reached a virtual consensus that global warming will occur over the coming decades. It remains unclear whether or not this warming has already begun, but we must recognize that the majority of those in the scientific community say that it will occur.

Besides expected temperature increases, it has been noted that other global changes are occurring, including stratospheric ozone depletion, loss of biodiversity, and general toxification of our environment, all of which can greatly affect agriculture.

All of these global changes are important, and I hope that our Government panel can tell us about the Federal activity on global changes in general.

However, our specific focus today is on the global-warming issue, and perhaps on another date we can return more fully to these other global-change issues.

The question I have for the witnesses today is: What do these climatic changes mean for our current method of conducting agriculture?

What types of research need to be done to help us understand how our agricultural systems will react, and to help us determine what changes need to be made in our production systems?

How will our Federal farm programs be affected, and indeed, should our farm policy planning take into account greater weather variability and uncertainty?

To what extent can we or should we promote practices which would slow the rate of global warming, such as planting more trees to tie up more carbon?

The popular press has clearly taken up the issue of our "Endangered Earth," as Time magazine so aptly titled its lead-off cover story in 1989.

These two subcommittees need to focus today on the degree to which our agriculture is endangered, not just in terms of food production, but in terms of agriculture as a tremendously important renewable resource that meets many of our national needs, and is so vital for our international trade and assistance programs.

I will now recognize our distinguished ranking minority member, who I am sure has some words of wisdom for us as we begin this hearing, Mr. Roberts.

OPENING STATEMENT OF HON. PAT ROBERTS, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF KANSAS

Mr. ROBERTS. I thank you, Mr. Chairman.

I want to commend the chairmen of both subcommittees for holding a joint hearing today. Mr. Volkmer and my good friend and colleague, Mr. Brown, but I hasten to add that Mr. Volkmer is also my good friend and colleague. [Laughter.]

The consciousness of the American public is at its highest sincerity since the early 1970's in regard to the environment, and I am certain we are going to have many more fruitful opportunities to deal with the issues of this nature in regard to the administration and this time period.

I feel perhaps a little more qualified than most to talk about the effects that the weather can have in regard to agricultural production.

More than most regions of the country, out in western Kansas we are at the mercy of the weather. We are called—or were called in earlier days "The Great American Desert." Mr. Chairman, we are indeed high-risk agriculture, and we are rapidly losing the com-

fort of irrigated farming, as the cost of irrigating from the waters of the Ovalala increase, why producers are forced to return to our very old tradition of dry-land farming. That is what every old timer at the coffee clutch says we needed to do anyway.

Needless to say, the dry-land Winter wheat farming will not be a big success this year in my part of the country. We are extremely dry. The Secretary of Agriculture recently visited central and western Kansas, along with Senator Dole, Senator Kassenbaum, and our Governor.

And I will say to my good friend, Mr. Volkmer, who always expresses an interest in our behalf, and in behalf of my district, that we are going to press ahead in regard to two disastrous instances, and the Secretary of Agriculture has promised us some expeditious handling of the failed-acre designation and the paying and grazing and emergency forage.

We are very dry, Mr. Chairman. We have some pasture ground out there that is in just terrible shape, and we have lost about half of the Winter wheat crop.

I recently cosponsored with Chairman Brown a bill, H.R. 1880, the National Agricultural Weather Information System Act. In an era of stealth bombers and space shuttles, we often, I think tend to forget the more mundane requirements of modern living.

We need better weather forecasting. I do not mean people, but better systems incorporating the latest technologies to reduce the uncertainties of weather forecasting, and then just as important, we need the superior methods of communicating that information to the farmer. That is a very important part of it.

Many aspects of this issue bear practical relevance to the farmer; however, our understanding of the broader implications that human activity on Earth may have on global climate change is less well understood.

I have seen many proposals, many headlines, many stories, many opinions as to how to fix that problem in regard to global warming; however, I am not yet certain we understand the problem, much less in a position to recognize the solutions, and that in part is why we are having that hearing and why I am a cosponsor of the chairman's bill.

I look forward to hearing the testimony from our distinguished list of witnesses, and I thank the Chair again for his leadership in this effort.

Mr. BROWN. Thank you very much, Mr. Roberts.

Do you have an opening statement, Mr. Volkmer?

Mr. VOLKMER. Yes, I do, Mr. Chairman. Thank you very much.

Mr. BROWN. The Chair recognizes the gentleman.

OPENING STATEMENT OF HON. HAROLD L. VOLKMER, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF MISSOURI

Mr. VOLKMER. Mr. Chairman, I too wish to join my good friend from Kansas in commending you for having these hearings and to review the phenomenon of global warming.

This is one of those areas where we seem to have far more questions than we have answers, as to both the causes and the effects.

The Subcommittee on Forests, Family Farms, and Energy is interested in global warming and climate changes for several reasons.

We are concerned with the long-range impacts of such changes on family farming operations and forest resources across the country. We also want to investigate the role that forest management may play in promoting or avoiding the warming effects that have been widely discussed.

I again wish to commend the gentleman from California for his leadership and foresight in this matter, and for his cooperation in developing this series of joint hearings.

It is our intent that today's hearing focus on the effects of global warming on agricultural crop production and on research efforts currently underway.

As I understand, at a future hearing we will look at forestry-related issues.

In passing I would like to comment to the gentleman of Kansas that perhaps if he grew a few more trees in his district, we may have a little less warming, and he may have some cooler air.

With that, I look forward to the witnesses' testimony today.

Mr. BROWN. Any other members desire to make an opening statement? I hope not, but the opportunity is here. [Laughter.]

Thank you. We have as our first panel a distinguished group of leaders from the Federal Government headed by Dr. Orville Bentley, Assistant Secretary for Science and Education at the Department of Agriculture; Dr. Alan Thomas, Acting Assistant Administrator at NOAA; and Dr. Shelby Tilford, Earth Sciences and Applications Division at NASA.

Would you gentlemen all come up to the table at this time. Some of you are not accustomed to appearing before the Agriculture Committee, so this may be a strange setting for you.

Mr. ROBERTS. Mr. Chairman.

Mr. BROWN. Yes, sir.

Mr. ROBERTS. I have a prepared statement from the Honorable Sid Morrison that I would like to have inserted in the record on his behalf.

Mr. BROWN. Without objection.

[The prepared statement of Mr. Morrison follows:]

PREPARED STATEMENT OF HON. SID MORRISON, A REPRESENTATIVE IN CONGRESS FROM THE STATE OF WASHINGTON

Mr. Chairman, let me begin by expressing my thanks to you for scheduling this hearing. Because of the obvious impact climate patterns and the "greenhouse effect" have on forestry and agriculture, I believe it is highly appropriate that we hear from the expert witnesses you have invited to testify before our subcommittees this morning. I'm also grateful for this opportunity because of my personal interest in this very important issue.

It is appropriate that we explore to what degree global warming can be minimized through changes in our current farming practices. Efforts to affect change in the emission of carbon dioxide resulting from deforestation; the development and release of methane in rice production, biomass burning and domestic animal production; and the emission of nitrous oxide from fertilizer use and biomass burning all have a direct effect on timber management and agriculture production practices.

Most importantly, in my mind, is the need for thorough and extensive research among the various Federal agencies which have a hand in the development of this issue. I'm delighted to have the opportunity to hear from representatives of three of the leading agencies charged with conducting this research, and look forward to

asking some questions which will help us better frame the global warming issue as it pertains to agriculture and forestry.

Thank you, Mr. Chairman

Mr. BROWN. Dr. Bentley, you are the lead off witness here. Would you proceed with your statement, which will be then be followed by the other two gentlemen, and then we will question all three of you as a panel.

Of course, we are very happy to welcome you again. You are familiar with this hearing room and this subcommittee, and our relationships have always been at the very best. So we are glad to see you here.

STATEMENT OF ORVILLE G. BENTLEY, ASSISTANT SECRETARY, SCIENCE AND EDUCATION, U.S. DEPARTMENT OF AGRICULTURE, ACCOMPANIED BY NORTON STROMMEN, CHIEF METEOROLOGIST, WORLD AGRICULTURE OUTLOOK BOARD; MIKE FOSBERG, RESEARCH METEOROLOGIST, FOREST SERVICE; DORAL KEMPER, NATIONAL PROGRAM LEADER FOR CLIMATE, AGRICULTURAL RESEARCH SERVICE; AND BOYD POST, FOREST BIOLOGIST, COOPERATIVE RESEARCH SERVICE

Mr. BENTLEY. Thank you, Mr. Chairman, members of the subcommittees.

The Department of Agriculture is pleased to be here today to talk about the topic of global warming. Perhaps I can depart a bit from my statement to say that it has always been a pleasure to appear before both of the subcommittees represented here on prior occasions, and I look forward to not only the professional purposes, but my personal feelings about that topic as well.

I would hope, Mr. Chairman, that my full statement would be included in the record.

Mr. BROWN. It will, Mr. Bentley, without objection, and you may proceed to present it in any way you wish.

Mr. BENTLEY. You have asked me to be rather brief, so I will try to highlight and recognize the time constraints that you have asked us to conform to.

I have the privilege of being the Department's member on the Federal Coordinating Council for Science Engineering and Technology on the Committee of Earth Sciences, or CES as it is called, and in that particular forum we have an opportunity to interact with all the other agencies that are involved in the questions of global warming.

So some of my remarks will reflect the concerns that have developed or the positions that have been developed as a result of preparing materials for the Committee on Earth Science of the affixed organization.

To help me today and to reflect the departmental involvement in this, I have with me Dr. Norton Strommen, who is the Chief Meteorologist for the the World Outlook Board; Dr. Mike Fosberg, the Research Meteorologist for the Forest Service; Dr. Doral Kemper, National Program Leader on Atmosphere of the Agricultural Research Service; and, Dr. Boyd Post, the Forest Biologist of the Cooperative State Research Service.

I introduce them for, one, as back-up, and two, to reflect that this statement is one that has been developed through the cooperations and the efforts of many people.

Mr. Roberts and others have already referred to the fact that this topic of weather and warming is not a new one for the Department of Agriculture and for agriculture. It is an age-old question, but new developments are taking place, and, Mr. Chairman, you referred to them in your opening remarks, and we fully concur with them.

The events that take place at a given time, like in 1988 the drought periods and high temperatures experienced in certain parts of the United States, give emphasis to the fact that changes might be taking place, yet there are still questions since we know that there are cyclic patterns in weather and climate, and, therefore, one has to think in terms of whether or not these changes fortail future directions, or are in fact a part of an evolving scenario.

This problem is very complex. It involves looking at air pollutants that have damaged crops and trees and have an impact upon health problems and other concerns of our country.

We have known for a long time that low-level ozone at the tropospheric level has an impact on crops, and we have been looking at that. Unfortunately, we have a back log of information.

We are mindful too that one of the ways we can attack these questions today is the use of computer simulation models. And in the Department of Agriculture, the use of these models will have an important role in helping us to develop future research and education scenarios as they relate to climate.

But we also recognize that it is important that we have laboratory data, field data, and studies to back up the work of these models to verify and validate the observations made, and that is true, of course, in many other areas of research.

Over time there has been a number of strategies looked at, and those date back to 10 or 15 years, although we make reference to some specific ones that have been reported already.

We are, as a result of changes with greenhouse gases and the concern over this, we are dealing with and monitoring the increase in the so called greenhouse gases, carbon dioxide, particularly, and its affect on plant growth. It has a positive affect in certain conditions. Methane, nitrous oxide, the chlorofluorocarbons, they all are a part of the global-warming situation.

The concern over ultraviolet light and its impact on plants is also being studied.

I can summarize very briefly the statement about what research is being done on global climate change really under two basic points.

Dealing with the impact that changing climate could have on the stability and productivity of our natural resources and the agricultural ecosystem, and second, developing strategies to reduce climate change by managing natural resources and the agricultural ecosystems to sequester carbon dioxide and reduce the emissions of other greenhouse gases.

We are taking a major role in this because it deals with the food production plants and animals and resources that are important to agriculture.

We are mindful too that there is a time factor involved. For example, in forestry, where four stands can be developed over a period of 50 to 100 years, we have to think in terms of changes and practices that we follow today and the potential for the future, and that's a subject that is being given a great deal of attention by the Forest Service.

We also point out in the statement the importance of changes and new approaches to research, not only using new technology and new scientific developments, but a philosophy that embodies perhaps greater attention to variables that might arise as a result of global warming have to be included in our activities.

We think of the Department of Agriculture, and I might say in my own bias opinion for other agencies, that they are a multidisciplinary activity as required.

We have to mobilize expertise from a great many places and I just want to touch on some of the areas within Agriculture, that is.

The World Agricultural Outlook Board is a hub for coordinating activities and getting information on climate change and meteorological impact on these changes.

The Agricultural Research Service obviously has had a long history of working with plant stress and the affect of climates, and we are very proud of the work that Mr. Roberts out in the drier parts of our country, and some of the data that is being drawn into the work in looking and evaluating change has come from some of the work that has been done at many stations, one of them being in Manhattan, Kansas.

The Forest Service has the most extensive research activity that is directed really to the affect of pollutants on tree growth. The Soil Conservation Service with its obvious importance and capability of assisting in helping the—or assisting in determining the impact of various changes, whether it be in moisture levels, temperatures, et cetera, on soil management practices. And the Cooperative State Research Service that brings into this mix the marvelous capabilities of our universities.

I want to also mention the Economic Research Service that is looking at these questions in terms of policy implications, and there could be many of some of the changes we talk about materialize.

And, finally, I want to make reference to an activity that you all know about, the Extension Service, that can help not only in policy analysis, but in helping to communicate and articulate to the farmers and ranchers of this country new practices that might assist them in coping with change should this change of the magnitude that it has been discussed occur over the next decades.

All of this, of course, is predicated on the assumption that we have to begin research now to be sure that we can evaluate a change, if it actually is occurring on a permanent basis, evaluating the ways that we can approach and deal with the question to ameliorate in some degree the impact of changes should take place.

So that does deal with management practices, the conservation of resources, the affect of temperatures and so on.

The Forest Service is mindful of the potential impact of using tree growth as a sequester of carbon dioxide in the carbon cycle. We also have a role in interacting with people from other agencies,

for example, energy that talks about reductions in fossil fuel emissions of carbon dioxide from fossil fuels. So that brings it into systems for meeting the energy needs of the American people.

The Forest Service has the Forest Ecosystem and Atmospheric Pollution Act of 1988 that calls for the Forest Service to make some long-term studies dealing with the very issues that I have referred to, and we outline them in the testimony.

In the Agricultural Research Service they are carrying on our cooperative work with Energy and will maintain the kinds of monitoring stations and observation that are important to evaluating where we are going.

We have initiated a program in the last year, or this year, on UVB, the effect of radiation, or the potential increase in radiation on crop growth and productivity, a topic, again, that has been studied, but is being revisited today because of the importance of the potential change in the reduction of stratospheric ozone and the possible increase of the penetration of UVB into the Earth's horizon.

I mentioned I have already talked to the work on the ARS, but here again we are looking at systems approach and utilizing computer expertise in cooperation with the Department of Energy and others.

I want to make one reference to the importance of trying to develop and to study the policy implications. I know that you hear dramatic statements occasionally about changes that might occur in terms of crop productivity in the United States, probably some of those are overstated, but there are continuing shifts in the way we can handle crops. Crops at one time that could not be produced in the Northern tiers of States in this country now regularly do produce some of the crops that were normally indigenous to the Central and Southern part of the United States.

Those changes are taking place due to the research being done on plant sciences and animal production, and the study of the ecosystem and the soil as it is affected by the enviornment.

My time is up and I should close by saying that the things I have touched on are just topic sentences of our statement, and we would be glad to elaborate on it.

I do want to say though in closing that the Department of Agriculture is an active member of the Intergovernmental Panel on Climate Change. It is an international body and we are participating both in the terms of the response studies for which the United States has the responsibility and the impact studies for which the Soviet Union has taken leadership, and we are active participants in this as well as in the developing of an overall strategic plan for global warming being led or under the auspices of the Committee of Earth Sciences.

Thank you very much.

[The prepared statement of Mr. Bentley appears at the conclusion of the hearing.]

Mr. BROWN. Thank you very much, Dr. Bentley. And I am also pleased that you brought your associates with you. We may be calling on some of them as we develop further approaches to this problem, and they need to see how an expert witness like you handles a difficult problem like this committee.

Our next panelist will be Dr. Alan Thomas, Acting Assistant Administrator for NOAA, and we are very happy to have him here this morning.

Dr. Thomas.

STATEMENT OF ALAN R. THOMAS, ACTING ASSISTANT ADMINISTRATOR, OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, U.S. DEPARTMENT OF COMMERCE

Mr. THOMAS. Thank you, Mr. Chairman and members of the subcommittees.

I am Alan Thomas, the Acting Assistant Administrator of NOAA's Office of Oceanic and Atmospheric Research. I appreciate the opportunity to present NOAA's efforts in global change research and climate services today.

As requested, I will focus on our interactions with national and international global-change efforts, and our interactions with the Department of Agriculture.

In NOAA's Climate and Global Change Program, we have recently embarked on a NOAA-wide program to address the global climate system with the broad goal of establishing a new national information service based on the achievement of reliable assessments and quantitative predictions of changing global climate, and associated regional implications on time scales from seasons to centuries.

This program builds on NOAA's role as an operational prediction and information agency. Specifically, NOAA's Climate and Global Change Program will address four scientific areas.

First is long-term observations; building on our current weather and satellite observing systems, the program will include an expanded ocean observing network, global sea level measurements, and monitoring the stratosphere to detect future change. This latter effort is done with NASA.

The second area is climate-process studies. This research seeks to understand and describe critical processes and conditions which characterize changes in the global climate system. Elements of research include a radiatively important trace species program to monitor, understand, and predict the role of greenhouse gases, such as carbon dioxide, methane, and ozone, in climate change.

Another element is the Tropical Ocean-Global Atmosphere Program, named TOGA. This international program seeks to understand interannual variability and develop predictive techniques for the phenomena.

And finally, we intend to pursue research on the hydrologic cycle and its importance to agriculture.

Third, our program of climate diagnostics and prediction will ultimately be the central component of NOAA's Climate and Global Change Program. This component will synthesize the results of the other programs into meaningful climate predictions, assessments, and related information.

The final element is climate data services. NOAA will support activities leading to climate data bases, data sets, and data fields to meet user requirements and to be easily assessable by those users.

The U.S. Global Change Research Program is an interagency effort to coordinate research on global change. This program is being developed through the Committee on Earth Sciences, a component of the Federal Coordinating Council for Science, Engineering, and Technology.

Seven Federal agencies, including NOAA, NASA, and the Department of Agriculture, are participating in the program. The goal of the U.S. Global Change Research Program is to establish the scientific basis for national and international policy making related to natural and human-induced changes in the Earth's system.

The U.S. program has three scientific objectives: one associated with monitoring; the second on understanding; and, third, predicting global change.

Monitoring of the Earth's system allows observation of any changes in the system. The data collected through monitoring can also be used to test models and predictions.

Many of the physical, chemical and biological processes need to be understood because of their effects on the global climate system. For example, the sources, sinks, and transport of chemical constituents and energy are not yet well understood; however, they have a tremendous impact on the climate system.

And, finally, models must be developed to describe and predict the climate system. These models will use both observational data and any new understanding of processes gained from the program.

NOAA's role in the U.S. Global Change Research Program is based on its history and experience with observations, analytical studies, weather and climate prediction, and information management.

Accordingly, NOAA will provide improvements in climate predictions and its regional implications on time scales from seasons to centuries.

Several international efforts are underway to investigate global climate change. The World Meteorological Organization and the United Nations Environment Program are sponsoring the Intergovernmental Panel on Climate Change, called the IPCC.

This panel will review the state of the science on climate change, review and conduct studies of social and economic impacts of climate change, and develop and evaluate possible policy responses.

The U.S. effort in scientific assessment is being coordinated through the Committee on Earth Sciences by Dan Albritton of NOAA and Robert Watson of NASA.

The scope of the assessment will cover all aspects of climate change with a special emphasis on identifying gaps in knowledge and a quantification of uncertainties. The assessment is scheduled to be given to the intergovernmental panel in September 1990.

The U.S. Global Change Research Program will collaborate with international global change programs. For example, the International Geosphere-Biosphere Program, under the direction of the International Council of Scientific Unions, is a major international effort to understand the processes which regulate the climate system, changes occurring within the system, and how the system is being influenced by human activity.

Lastly, I would like to talk about NOAA's current climate services. NOAA will continue to provide climate services as its Climate and Global Change Program works toward its goals.

The NOAA Climate Analysis Center monitors, diagnoses, and predicts short-term climate fluctuations. This center produces monthly and seasonal outlooks, and weekly and monthly analyses.

The Joint Agricultural Weather Facility is a cooperative effort between the Climate Analysis Center and the Department of Agriculture. This group publishes the Weekly Weather and Crop Bulletin.

Also, we are working on an agreement between the Climate Analysis Center and the Forest Service to formalize working relationships for enhancing fire weather services.

I would also like to mention that during last summer's drought, the Climate Analysis Center published the Weekly Drought Advisory Report, incorporating information from several Federal agencies. The reports were distributed to Federal administrators, congressional staff, private industry, and the media.

NOAA's National Climatic Data Center collects, archives, processes, and disseminates climatological data, develops analytical and descriptive products, and provides historical analyses and interpretation of climatological data.

NOAA, through the National Climate Program Office, supports the Regional Climate Centers. These centers address the regional and local aspects of climate, and they interface with the Federal Climate Analysis Center and the National Climatic Data Center.

Also, during the drought of last summer, the Department of Agriculture and NOAA, along with several other Federal agencies, cooperatively produced a report named U.S. Drought 1988: A Climate Assessment. This report accompanied the report to the President by the Interagency Drought Policy Committee.

The NOAA research laboratories support climate services and are addressing climate issues, some of which impact agriculture.

NOAA's Geophysical Fluid Dynamics Laboratory develops weather and global climate models to improve our ability to predict climate variables such as soil moisture and precipitation.

We expect the new seventh generation supercomputers to provide the capability for incorporating complex processes, such as the land surface exchanges, to improve climate models.

NOAA's Air Resources and Aeronomy Laboratories are investigating why high levels of ozone exist in rural areas. This is important because of the foilar plant damage ozone can cause.

In conclusion, NOAA is much involved in the science issues surrounding global change, and in providing available climate information and data for use in U.S. decisionmaking.

NOAA's Climate and Global Change Program will coordinate with the national and international efforts to understand the climate system, and to ultimately predict what will happen.

This concludes my prepared remarks, and I would like to ask that my entire statement be submitted into the record.

[The prepared statement of Mr. Thomas appears at the conclusion of the hearing.]

Mr. BROWN. Without objection, the entire statement will be in the record, Dr. Thomas, and we appreciate the excellent summary you have given us.

Our last panelist is Dr. Shelby Tilford from the Office of Space Science and Application of NASA.

STATEMENT OF SHELBY G. TILFORD, DIRECTOR, EARTH SCIENCE AND APPLICATIONS DIVISION, OFFICE OF SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. TILFORD. Thank you very much, Mr. Chairman.

I too would like to have my written testimony entered in the record.

Mr. BROWN. Without objection, it will appear in full.

Mr. TILFORD. Thank you.

In my written testimony I have tried to describe very briefly the current state and knowledge of climate change, an outline of the scientific assessments of global climate change that will be conducted as described earlier under the auspices of the International Panel for Climate Change, the type of scientific information needed to predict future global climate changes, and, finally, the scope and content of NASA's Earth System Science Program, how it has coordinated with the scientific community in general, other Federal, and specifically the Committee on Earth Sciences, international agencies and programs, the International Geosphere-Biosphere Program, and the International Council of Scientific Unions.

It is evident today that the Earth is characterized by change. We have entered an era in which the human race probably has achieved the ability to alter its environment on a global scale.

Ozone and global greenhouse warmings are just two of the interrelated environmental issues we face today. Others include such issues a deforestation, desertification, acid rain, and river and oceanic pollution.

To gain a significant scientific understanding of how human activities will effect the Earth's environment, we believe requires a new approach to Earth sciences as described in the Earth Systems Science Report, published by NASA about 2 years ago.

At present we do not know the relative contributions of natural processes and human influences on these changes. As stated by Dr. Bentley earlier, we believe that the thrust of the future has to be an Interdisciplinary Research Program.

We now have compelling evidence that the chemical composition of the atmosphere is changing at a very rapid rate on a global scale.

Atmospheric concentrations not only of CO_2, but also of methane, nitric oxide and the chlorofluorocarbons are currently increasing at rates ranging from 0.2 to 5 percent per year.

The atmospheric abundances of these trace gases is higher today than during any period of recorded observations, and that goes back 160,000 years from some of the ice core samples.

While there are current general circulation models, GCM's, predict an increase in global mean temperature between approximate-

ly 2 and 5 degrees centigrade for an effective doubling of atmospheric carbon dioxide.

There are significant differences in the magnitude of the predicted regional and seasonal temperature changes. Similarly, it should be noted that while all GCM's predict an overall increase in global precipitation, predictions of changes in the amount of regional precipitation differ even in sign for key areas in the continental United States.

Therefore, it is our opinion that GCM's are currently not capable of reliable predictions of climate change at the regional level.

Other kinds of human activities that can lead to global change include, of course, industrial effluents, fossil fuel burning, refrigerating agents, aerosol and solvent usage, and land practices involving agriculture, food production and deforestation.

We now know that there is a massive ozone depletion over the Antarctic, with implications for ozone depletion at midlatitudes in the stratosphere.

Tropical forests are being depleted with a possible consequence of global change. Marginal lands are being converted to desert by nonconservative agricultural practices with implications for regional climate change.

The effect of man on the environment must be quantified and understood in the background of natural change. This requires a much more intense understanding of the Earth's system than we have today.

A better understanding of the Earth's system and the development of the ability to predict long-term global change as part of the Earth's system are the foundation of the U.S. Global Change Program.

I think some examples are the impact of the 1982-83 El Nino event that caused billions of dollars of loss, the 1988 summer drought was probably the result of natural fluctuations in the climate system, perhaps super imposed on a possible long-term warming trend.

The consequences of global change need to be predicted whether occurring by natural or man-made causes. In order to develop wise policy to deal with such changes and some mediation of these effects.

Energy, agricultural, natural resources, costal zone, and water resource policies will all be influenced by significant changing climate.

If we want to understand how changes in the physical climate system will impact agriculture and energy policies, we need to improve our scientific knowledge of ecosystems to respond to these changes.

As was mentioned earlier, the Committee on Earth Science, the FCCSET, Federal Coordinating Council on Science, Engineering and Technology is making an effort to develop such a plan as was submitted with the President's fiscal year 1990 budget in "Our Changing Planet: A Strategy for Global Change Research", I think lays out the direction we need to go.

This describes the primary questions, what forces initiate global climate change; how does the Earth's system respond to changes

and forcing functions; how has the Earth's environment changed the planet; and, how well can global change be predicted.

Right now we are not doing very well in most of these aspects. In terms of the elements that were described earlier by Dr. Thomas, the NASA portion of this plan is based on a continued strong support for the NASA Research and Analysis Program, expansion of the concept of interdisciplinary research, continuation of the upper atmospheric research satellite to better understand the stratosphere, the Ocean Topography Experiment, TOPEX/POSEIDON, a joint U.S. French Effort, the NASA Scatterometer to better understand ocean circulation and its impact on climate.

The NSCAT, of course, is planned to be flown on a Japanese satellite in the future. And then finally initiation of the planned Earth Observing System, which in conjuction with the polar reading meteorlogical satellites will provide us a global data base of which we not only can develop models, but also detest models.

The heart of the whole issue, however, is to establish an information system whereby both scientists, farmers, foresters, et cetera will have access to this data on a global basis.

In addition, NASA and the United Nations Environmental Program are working on a data base system to help provide a global data base informations system to the world as a whole.

One particular issue that we would like to promote and continue is we believe it is extremely important to have a separate sciences and policy approach to doing scientific assessments.

Our experience in the stratospheric ozone issue, I think we learned a number of lessons. It was found essential in the stratospheric ozone issue that there is clear separation between scientific assessments and policy assessments; that there be a continuous dialogue between the scientific agencies and the regulatory agencies and policymakers to ensure that the scientific information that is required for decisionmaking is obtained and presented in an adjustable form; that the participants of the scientific assessment are the best scientists in the world, and also representative of the international scientific community, not just a single country; that scientific research programs are developed and implemented by the scientific agencies in concert with the scientific community, including the National Academy of Sciences; and that there is very close coordination among the scientific agencies charged with conducting such research.

We believe one reason that we were able to reach international agreement with the U.S. lead role in the stratospheric ozone issue and the regulatory aspects with respect to the CSC's was that a broad research program was structured that developed sophisticated techniques for ICSU and remote sensing observations from balloons and aircraft to study the many topics related to the CFC ozone issue.

And, two, stable rigorous long-term program for studying stratospheric ozone was supported by the Federal Government. That goes for NASA, NOAA, National Science Foundation, and some of the other agencies.

I think this is an extremely important lesson for the U.S. Global Change Program, which encompasses a much larger suite of global change issues, and involves a large number of Federal agencies.

I think Alan discussed the approach in terms of the international scientific assessment on climate change to the IPCC. We fully support that and we are participating with the other agencies as CES in this respect.

I will not go into the NASA Research Program, which I believe contributes significantly through a number of collection observation field experiment process studies and theoretical analysis, and hopefully a new initiative in archiving and having access to data in conjunction with the USGS and NOAA.

Understanding all of the issues in global change is clearly a priority for the scientific policy communities. This will require a comprehensive coordinated national and international research effort, wise policy decisions requiring improved understanding in the way we live in, impact, and change the Earth's environment.

From the NASA point of view, we believe that global data sets are extremely important. The satellite data from the current operational satellites, as well as those for planned Earth observing systems can provide the data sets required to document and understand global change.

At present the ability to measure many of the needed ocean land and atmospheric parameters has been demonstrated; however, there are presently very few global data sets of any kind of the quality and length necessary to contribute to document global change. A prime example is the deforestation issue in South America.

If we wish to have available in the future a documented data base of global change, be able to delineate between natural and man-made parameters, we must begin now to establish those systems that will attain required data, and I believe that NASA is firmly committed to working closely through the Committee on Earth Sciences with all other Federal agencies and international organizations.

Thank you very much, and I will be happy to answer any questions you might have.

[The prepared statement of Mr. Tilford appears at the conclusion of the hearing.]

Mr. BROWN. Thank you very much, Dr. Tilford, for that very comprehensive statement, and even more comprehensive report which you have submitted in connection with it.

The panel will now accept questions from members.

Mr. Roberts, would you like to start?

Mr. ROBERTS. I will be happy to start, and I will do so by yielding to my colleague, Mr. Walsh.

Mr. WALSH. Thank you, Mr. Chairman, and thank you leader.

I had a question that I was going to ask of the second panel, but time constraints will force me to ask it now, and I would hope that you could respond.

There have been some comments on the fact that the planting of more trees could slow the global-warming trend. Is this indeed true, and what other steps could be taken through agricultural practices and programs to result in positive climatic changes?

Mr. BENTLEY. Mr. Chairman, I would like to call on Dr. Fosberg to comment on that question, if I may.

Mr. BROWN. We would be happy to have him respond, Dr. Bentley.

Mr. FOSBERG. My name is Michael Fosberg from the Forest Service, and to answer your question of the role of trees in the carbon balance, all of the carbon that is in wood comes from the atmosphere. It is taken up as carbon dioxide in the photosynthesis process, but as long as we have growing trees, we are sequestering carbon in wood.

If we allow the forest to live its natural life, that is the germination of the tree, the growth of the tree, the death and ultimate decay, we have a carbon-neutral environment; that is the carbon is returned back to the atmosphere through the decay process.

If the wood on the other hand is sequestered in the form of long-term durable forest products such as furniture, then we have effectively removed it, not permanently from the carbon cycle, but certainly for a very long period of time, and that will offset the carbon dioxide put in from the consumption of fossil fuels.

Mr. WALSH. Are there any other plant species that fix carbon as well as trees and that could be planted commercially or agriculturally?

Mr. FOSBERG. All vegetation fixes carbon. They all contain carbon and it is all derived from the atmosphere, the carbon dioxide in the atmosphere through the photosynthesis process.

In the case of nonwoody plants, we have vegetation—we have material which potentially goes through a life, death, decay process more rapidly.

Mr. TILFORD. I would like to comment, if I might, please.

I certainly believe that trees are a temporary source of carbon. I think they do as prescribed uptake carbon, however, I believe our understanding today is such that we think this is a short-term storage mechanism. I mean trees grow, they die, and so we are talking about a few tens to perhaps the maximum of 100 years or so.

That is extremely important. I believe the most serious issue with trees and forest, however, is not the impact they perhaps have on carbon dioxide, but the potential impact they have on precipitation.

I think what models are telling us today that the evaporation from plants or trees is one of the most important elements in determining rainfall patterns.

And so, I believe that even though trees are essentially a short term of continuation of some of the carbon dioxide issues, that perhaps a much more serious problem with deforestation is very significant changes in rainfall patterns throughout the globe.

Mr. WALSH. Thank you, Doctor.

Mr. BROWN. Would the gentleman yield briefly just to clarify what I think I heard here?

Mr. WALSH. Yes, sir.

Mr. BROWN. What you are saying is that the carbon uptake in vegetation is essentially a neutral process over the life of the plant. For trees it is a little longer, and if the tree is converted to a long-term product like furniture or a house or something, it is stored a little longer, but it is still a short-term process and it is carbon neutral in that cycle. Is that correct?

Mr. FORSBERG. That is essentially correct. It is carbon neutral, there is no permanent removal of carbon from the carbon cycle in a natural process. The difference comes from long term durable storage, that is as forest products, wood products, furniture.

Ultimately that decays as well. We have some products which last thousands of years, others are much shorter.

Mr. BROWN. There is a slight extension of this that I want to ask you about. In the event that there is a major change in the balance of plants on the Earth's surface, in other words, a major deforestation as an example, doesn't this produce at least a temporary surge in the amount of carbon in the atmosphere, and on the other hand, wouldn't a major increase in the planting of forest or other carbon base plants, wouldn't that if it were a major increase result in a at least temporary reduction in the amount of carbon in the atmosphere?

Mr. FORSBERG. That is exactly correct. With deforestation we would have a surge of carbon in the atmosphere, and with major reforestation we would have a net removal.

Mr. BROWN. And then we would achieve a new stable balance around that new state?

Mr. FORSBERG. That is correct. The carbon cycle would become neutral, but at a lower level of carbon dioxide.

Mr. BROWN. I just wanted to make sure I understood that.

Mr. WALSH. I yield back to Mr. Roberts, Mr. Chairman. Thank you.

Mr. BROWN. All right. Mr. Volkmer. He wants to pass for the time being.

Mr. VOLKMER. Dr. Bentley, as I understand, one of USDA's Federal research grant programs is designed to provide funding for research on the effects of stratospheric ozone changes.

Will the Department be broadening this program to look at the impact of other atmospheric changes, such as the increasing levels of carbon dioxide and other greenhouse gases?

Mr. BENTLEY. Yes, the answer to that is yes. We are looking at several aspects, for example, in carbon dioxide in terms of what an increase—and there is always two sides to these issues—frequently two sides to it. One of them is that an increase in carbon dioxide could stimulate plant growth under certain sets of conditions. So we are looking that that question.

But the main thing right now I think we are looking at monitoring increases and working with other agencies to determine what that increase is to see what in fact it would have in terms of carbon dioxide.

In the terms of ozone, we are very much concerned that the ozone increase in terms of low level are tropospheric. We think that is a major—of the pollutants our research people tell us that ozone is the most—has the most damage or the most potential damage and in right now damaging more of our plant products than any other pollutant in the air, and we are stressing that and working with that. We need more studies.

The trouble is we can have, I think, 10 locations where we are looking at that seriously, and that is not really enough and Dr. Thomas referred to the level of ozone and air in rural areas. We are looking at cities—the EPA is looking at cities and the non-at-

tainment of standards there, but there is a whole series of questions about ozone in the air in general and rural areas because ozone, as I understand it, is easily transported in the air and we are running into questions of ozone in areas where it is not necessarily in or immediately adjacent to large populations where heavy transportation is taking place.

We are looking at all of these. The answer is yes.

Mr. BROWN. Did you comment on that, Dr. Thomas?

Mr. THOMAS. Yes, I would like to comment on that. Our scientists think that both rural and urban ozone are the key air quality issues in the next decade. Let me go to the urban areas. We control the hydrocarbons, but not the NO_x, the nitrogen compounds in combustion from automobiles and other sources, in order to lower the level of ozone in our cities. What can happen is the nitrogen NO_x, compounds can be transported into the rural areas. There they can find natural hydrocarbons and interact to produce ozone in rural areas. So, you have a problem such that the chemistry that makes ozone can occur in rural areas and that is why you see very large regional elevated levels of ozone, particularly in the summertime when there is a lot of sunshine for photochemistry to occur.

And, you find that the distribution of where the rural ozone is high does not correspond to the distribution of where you produce your nitrogen oxides. So it would have to be a transport process by which this occurs.

Mr. VOLKMER. That leads me to another question I have, and, Dr. Tilford, I would like for you to comment on too. When I see what pictures I have heard about like the picture of the ozone-depleted layer in the Antarctic, but we are not releasing a lot of chlorofluorocarbons et cetera in the Antarctic, but we see a loss there.

Are we not concerned about the whole global atmospheric changes and how they effect different areas, or is it just because—in other words, if I release chlorofluorocarbons in Washington, D.C., does it just stay here and do I just worry about it here, or do we have a movement of the warming gases as well as the ozone depletion gases?

Mr. TILFORD. I think it is very dependent, sir, upon the lifetime—what we call the tropospheric lifetime of some of these compounds. Let me diverge for a moment.

The great thing about chlorofluorocarbons is that they are inert. I mean that is why they work so well in refrigerators. They do not clog up systems. They worked well in spray cans. They are not very toxic; have all the great qualities, except they last a long time in the atomosphere.

We thought that was no problem until 1974, and we found that when they diffuse into the stratosphere, then photo decomposition releases free chlorine and this free chlorine then destroys catalytically the ozone in the atosphere.

This is a completely different question than ozone in the troposphere. We believe it currently takes approximately 3 to 6 months for a complete atmospheric distribution of compounds in the troposphere; that is we can release CFC's in Canada and they will diffuse to the equator in a few months.

So things with long life times and those that are inert are primarily impacts on the stratosphere. What we are talking about in terms of tropospheric ozone is short life time compounds, such as the $N2_o$ and NO_2 compounds that come out of combustion, whether it be internal combustion engines or smokestacks.

These are much shorter lived and because of scavenging making ozone et cetera in the troposphere, these are more regional problems than global problems, for the most part; however, we have been noticing that the concentrations of things like methane have been increasing extremely rapidly over the past 10 years. This has not only regional implications, but global implications. So for some things the long life times are good, they are global. For the shorter life time species, it is primary regional.

Mr. VOLKMER. So what I understand, correct me if I am wrong, that we need to direct our research on a localized regional basis on some things, and on other things on a global basis. Is that correct?

Mr. TILFORD. I believe that is correct, sir. I think we need to understand what we call sources and sinks, where things come from and where they go. Those are mostly local to regional aspects. On the other hand, we need to know how they are distributed on a global basis and what the global impacts are.

So, yes, we need a program that only looks at the global prospective, but it also looks at the local regional and its discoupling between the sources and sinks that will be very important in telling us what kind of policies we need to make in the future.

Mr. VOLKMER. Is the IGBP the avenue or way to go as far as the global research is concerned?

Mr. TILFORD. I believe that what the scientific community is trying to develop and what the U.S. Federal agencies are trying to coordinate through the Committee on Earth Sciences is an ideal approach to the global perspective.

Mr. VOLKMER. That includes the union and——

Mr. TILFORD. Yes, that includes the IGBP, which is coordinated by the International Council of Scientific Unions, yes. That is an international body. It is going to take several years to get the international program off the ground. In the meantime, what the Committee on Earth Sciences and the U.S. Global Change Program is trying to do is help define those scientific issues, the ones that are most important, and the ones that we need to address first.

Mr. VOLKMER. I know I have taken more than my time, but I do have one other question. It is always interesting to me to expand the structure of our trees globally, and now we are saying, well, we have got to do something about what is happening down along the Amazon. But here in the United Staets over a period of, I guess, the last 100 or 200 years we have cut down a lot of trees, have we not?

Mr. TILFORD. But we have planted a lot of trees also, sir.

Mr. VOLKMER. Do you think we are about even?

Mr. TILFORD. I think we probably have more trees today than we had 100 years ago, but I will have to defer to the experts.

Mr. VOLKMER. I do not know. I wasn't here then. I do not know anybody that was. I do not know if we had a record, or if we counted the trees, but that was curious to me, the question of whether we did or did not.

Mr. TILFORD. No, we did cut down a lot of trees. I think though in terms of some of the forestry programs today and some of the paper companies, et cetera, we are planting a huge number of trees in the United States on a daily, weekly, monthly basis, but I do need to defer to the USDA on this particular issue.

Mr. BENTLEY. That is essentially true that there has is—well, in most inventories, while it may change in location, there is more lumber and more out there now in forestry products now than there was a few years ago. There was an increase.

Mr. VOLKMER. You really are following the provisions of sustained yield in the Forest Management Act then?

Mr. BENTLEY. That is what they are trying to do. Well, when you talk about the planting of trees, I had the privilege of being helicoptered over a large area of the northwest in a large part of the forest area, and it is amazing how well that has been replanted and what the concentration is now.

That does not apply to every area, but it does apply in a broader sense and I think that is something that our Government has encouraged and I commend the Congress for its interest in this topic because that has been important both in tax policy and in conservation policy, and the effort of the private sector to comply with this.

Mr. TILFORD. Especially economic policy.

Mr. BENTLEY. Economic policy, that is right.

Mr. VOLKMER. I am going to close with this observation. I will go back to it. Undoubtedly I had already envisioned that 200 years ago there were a lot more trees than there are now in places like Washington, D.C., and New York, and Manhattan, and St. Louis, and Cleveland, and all the large metropolitan areas, that surely there were some trees there where there is now concrete. And isn't that a depletion and couldn't we try to replace more trees, grow more trees?

Mr. TILFORD. The distribution has changed significantly. I think we all concur in that, but in terms of the total number of——

Mr. VOLKMER. The total number we may be about equal.

Thank you very much, Mr. Chairman.

Mr. BROWN. Mr. Olin.

Mr. OLIN. Thank you, Mr. Chairman.

I would like to congratulate the panelists on their presentations. I was a little disturbed, however, I do not think anyone of you, with maybe the possible exception of Mr. Tilford, really expressed any degree of discomfort, I know you must feel this on these subjects, but the things that really are in our minds are questions such as, how severe are these warming trends, the questions of pollution, how soon are they going to affect us, how soon is the food supply in this country going to be in anyway threatened.

I think you all said that we do not know enough. You described activities that were going on. And I think you all said that you do not think that we know enough about what is happening to be sure what to do about it, but I do not think, with the possible exception a comment Mr. Tilford said that we are not doing well on research, I think you said that—none of you indicated any urgent call to action as to more activity on the research front or more coopera-

tion, or more integration, or more action on particular pollutants or something of that sort.

I wondered whether you could each comment a little bit more on your sense of discomfort in this area, and to what extent would you call upon the Congress or the Government to do more about knowledge and correction of trends that appear to be accelerating in the wrong direction.

Maybe I could ask Mr. Tilford if you could comment first, and we will go across the panel.

Mr. TILFORD. Thank you very much. Please do not accept my statements to be taken as that in many areas we do have very serious concerns. In many areas we do not know whether we have concerns or not.

I think truly in the case of some of the effluent emissions, some of the emissions in terms of chlorofluorocarbons we have supported very strongly the policy based upon the recent observations in Antarctica and both in the Arctic that we believe that a full phase out of CFC's on a global basis is extremely important.

We I think in this case have done enough research to understand that the CFC's themselves are detrimental to stratospheric ozone. We have observed massive depletions in both Antarctica. We have observed major depletions in the Arctic.

We have watched the concentrations of free chlorine and chlorine oxide grow as the ozone depletion is observed on a day-to-day basis on satellites. So between our ensitu measurements and the satellite measurements from space, I think we have a very good idea in some cases.

Now I think also this concern about regional pollutants is extremely large. You can go to L.A. today and you will be very lucky if you can see the mountains just outside the city of Pasedena, and the frequency which you can now see the mountains has probably improved in the last 2 or 3 years, but still there are more days when you cannot than when you can. That is a very serious issue in terms of effluents.

However, on the other hand, I believe because of regulations with respect to automobile effluents, we are probably better off today in the case of L.A. than we were a few years ago.

I think we have fewer things coming out of tailpipes today than we did a few years ago.

Let me get to the larger issue though, and the larger issue is the global-warming issue. It is not as simple as the chlorofluorocarbon issue where we can regulate on an international basis because they are all man-made.

In terms of the CO_2 issue, we are talking about the pure survival of a large number of individuals in the world and developing countries. How do we not burn wood? How do we not run factories? These are much more complex issues.

On the other hands, their models are much less complete, I believe, than our understanding of stratospheric ozone. The major—or one of the major uncertainties in the global-warming issue is the effect of clouds. Today clouds are treated in most global circulation models simply as the statistical input.

We do not know what on a 5-year basis, we probably know for 3 years now due to a concerted effort between the World Meteorolog-

ical organization, NASA, and contributions by NOAA what cloud statistics are for the last 4 years.

We do not yet have sufficient information of whether additional evaporation due to global warming is going to cause more clouds, and at what level or what altitudes those clouds are.

Why I say that is important is if you have low-level clouds, you get an increase warming effect. Or if you have high-level clouds you get a cooling effect.

So by varying the altitude of clouds, which is a natural phenomena by simply a few kilometers, an increasing number of clouds can either enhance the global-warming effect, or it can negate the CO_2 and CFC trace gas-warming effect.

Our models are not good enough to date to tell us that. Furthermore, in the areas which I think are most important is what is going to happen to precipitation. I think the total world food chain is dependent on precipitation. If we have too much of it, it slows it down. If we have too little of it, it slows it down even more.

So without doubt I think one of the most important things that we need to better understand, one, is what is global precipitation today, how is this distributed throughout the world.

We do not measure that very well simply because 75 percent of the world is ocean, is we do not have ships where most of the precipitation takes place. We would like to be able to do that from space, and we are trying. It is one of the most important parameters we can measure and understand because it also tells us how much energy is transferred from the equatorial regions into the Northern/Southern Hemispheres.

But our models are completely incompetent or unable to predict regional precipitation patterns. I think in the Midwest of the United States, the Wheat Belt, our irrigation practices are fine for a few years, but once we deplete the aqua we may very well wind up the same place we were in the 1930's and no solution this particular time.

So we are very, very concerned. We are very concerned because there are models are unable to predict what precipitation patterns are going to be under different scenarios of warming. So we do have concerns. We have big concerns. We think——

Mr. OLIN. If I could interrupt you.

Mr. TILFORD. All right. I am sorry.

Mr. OLIN. I want to hear from the other two before my time is out.

Could you express your opinion of to what extent are you calling for more research activity, or do you think what we are doing right now is enough?

Mr. TILFORD. Unless we have better measurements, long-term measurements in order to detect trends, and unless we have better models, which can do a better job of prediction, we are going to be in the same boat 20 years from now that we today. Therefore, I think we——

Mr. OLIN. You did not answer my question.

Mr. TILFORD. Therefore, I think we need more research in these areas.

Mr. OLIN. Like what order of magnitude, times two, or——

Mr. TILFORD. I am afraid, sir, that before I tell you that I will have to get approval from the administration.

Mr. OLIN. OK.

Mr. TILFORD. I will submit to you this year, hopefully, what we think is rational intelligent, and I hope, correct approach in order to provide the global measurements.

Mr. OLIN. I think we would be interested in that.

Dr. Thomas, if the chairman would allow me to finish the other two people on these questions.

Mr. BROWN. We will count it as all one question. [Laughter.]

Mr. OLIN. It is one question.

Dr. Thomas.

Mr. THOMAS. Sure. I must say that I did not intend in the testimony to—not to seem that we were very concerned about the issue. We think climate and global change are really very important issues.

Climate is an issue on a year-to-year basis, as well as on the longer-term impact. We in NOAA are interested both in the natural fluctuations in climate, such as the results of El Ninos that have occurred in 1982–1983, and 1973–1974, and their effect particularly on agriculture and a lot of our economic activity, and we have tried to address those in our programs.

In the area of global change, we fully support the effort that the administration has put on the table to try to direct attention to the issue of what is happening to our global environment, and we consider in there not only the greenhouse effect and stratospheric ozone, but also the regional implications, ozone on the regional scale, which is a very important problem, one that we have tried to pay some attention to and tried to raise the interest of people in these areas.

So we do have a sense of urgency. To put it in terms, you have asked—our request to the Congress in 1990 is about a factor of two above our 1989 request for global change. So we do in fact believe it is a very important area. It is one that we hope the Congress is interested in, and we are working through, as Dr. Tilford had mentioned, the Committee on Earth Sciences to bring these issues to the attention of the administration.

And I think when I summarized in my testimony, I tried to hit the areas that we thought were important, for example, the issues of the greenhouse gases. We started on that program more than 5 years ago. We are still asking for funding in the 1990 budget to continue that program. These gases are where some of the early warning signals can be found. We have been able to put together data on what is happening in the methane area. We have a 30 year record on carbon dioxide. We are looking at ozone.

So in the NOAA program we have tried to pay a lot of attention to climate change. I would mention one other thing, the role of the ocean. That is not something maybe this committee discusses, but we worried about tying up carbon dioxide.

One of the unknowns is what is the role of the ocean. There are processes in the ocean that actually could tie up carbon over centuries. The formation of carbonates and the deep circulation can tie up carbon materials over millions of years. So that is a potential long-term removal mechanism. We really do not understand how

much carbon is in the ocean right now, and that is a focus of the NOAA program, and it is one of the unknowns that is illuminated in the Federal plan.

I could go on with a number of other areas, but I will just leave it right there and say that we are very interested in this issue.

Mr. OLIN. Thank you.

Dr. Bentley.

Mr. BENTLEY. I would like to just hit on some points very quickly. One is that we have to remember that in the plant science work that we do, all of it is a big emphasis on the climatic effect as a major function of our research programs, both in universities and in the ARS and the Forest Service for a long time. We want to put additional stress on that.

On the food supply question, I will be quite candid. We have been through a process of time when the mind set of many people has to do with surpluses. So when you begin to talk about supplies, and I am on a lot of working groups, and I just had an exchange yesterday that was very extensive about the question whether or not we should be looking at these issues, because isn't the big problem having to do with with over supply of food rather than under supply.

That is mind set that we go through about every 10 or 15 years it seems to me, and we are in that process now.

I think we need more research in special areas. And as a part of the global change report, I just support what my colleagues have just said in these areas without elaborating on it.

We have been looking at ozone, for example, and the damages, and I think it dates back some 15 years. We have a difficult time getting sufficient resources to do this because we should have more monitoring locations than the 10 that we have. So we would hope to expand there.

The Forest Service is really making a major decision about allocating their resources and they have asked for an increase, and it is part of the 1990 budget request, to really look at air pollutants in terms of forest production. And I think that is a major thrust and I really commend the Forest Service for taking that initiative. Because at one time there was a management question, more emphasis on straight production systems and harvesting, et cetera, where now they are looking more at these kinds of questions.

I also think that we are going to link in with the international activities so that we better understand what it is—we really should not commit to activities until we get the kind of meteorological and climatology as needed for us to say, well, where are we going, because then we can begin to set up our research, and I want to commend you on the comment, Dr. Tilford, on clouds. That is a very important thing.

We may place that it is conceivable if there is changes in temperatures and world circulation patterns, areas that are now dry may become wetter, or wetter areas may be drier, or wetter. There is all of those kind of combinations, and that is why in our Competitive Grants Program, sir, which you know about, in our discussions at earlier times, we want to stress the matter of looking a basic plant physiology as related to stress because there is a lot to learn about what plants can do to cooperate, and I could go on

more, but I think we are concerned and I can say to you that the concerned agencies and universities are deeply interested and concerned with this issue.

Mr. OLIN. I appreciate the response of all you three gentlemen. I think your level of uncomfortableness is very evident and I appreciate your comments.

Thank you, Mr. Chairman.

Mr. BROWN. Thank you, Mr. Olin.

Mr. Morrison, do you have any questions?

Mr. MORRISON. Mr. Chairman. I am sorry I missed some of the earlier part of this. I will read back the testimony. I wanted to ask some questions. We are very proud on the Forestry Subcommittee, particularly led by our former chairman, Charlie Whitley, that aggressively pursued the question of vast deposition and questions of Dr. Bentley.

I wondered if perhaps that aggressive approach has given you the flexibility to broaden USDA's look at the total atmospheric-pollution issue so that you sort of have a head start on some other agencies on the question of greenhouse gases and global warming?

Mr. BENTLEY. Mr. Morrison, that is absolutely right. In other words, where the funding and the activity is going right now in the Forest Service, it really is an outgrowth of the work that was done over the past 10 years on acid rain and assessment study that is coming to a close. The final report is due to be submitted in 1990.

That has led and has assisted the Forest Service to get allocation of resources and they are getting some people who are mobilized that can do these kinds of research work, and in short the answer is yes, and that is a continuation of studies having to do with the environment. And I think they are projected to go for at least one or two—at least two decades into the future if everything goes as they are now planning.

Mr. MORRISON. I am delighted at that response. I think we will have to share with our colleague, Mr. Whitley, the enthusiasm lives on.

Just one question on methane, Dr. Bentley. We know it is a contributor to greenhouse gas. It is a problem. Is USDA looking at that?

Mr. BENTLEY. The answer, of course, is yes. We are monitoring the methane increases. On the other hand, I do not right at the moment think of ways in which we can cope with the question on terms of livestock production, that is an important part of the utilization of our grasslands, et cetera. The marsh lands in places where some of the methane comes from is an important part of our wet lands preservation concept and it is important to endangered species and wildlife. So that is one of the questions. With regard to rice production, I think we are looking at how it is generated and so on, but I do not know of any of work where we are talking reducing methane other than perhaps the obvious one, changing to different cropping methods.

I stand to be corrected by more careful scientific observation, but I would presume that more wetland rice production would tend to reduce methane problems, but that would also reduce yields, and the systems are growing, and where one could go.

So that is a problem that I think will be looked at both on the U.S. side and as a part of the IPCC, the international one. That is where the methane question has to be looked at as well.

Mr. MORRISON. Thank you.

Thank you, Mr. Chairman.

Mr. BROWN. Mr. Stenholm.

Mr. STENHOLM. I believe what each one of you are indicating is that we lack many of the needed answers. In fact, we need to utilize our limited resources in seeking out the answers to what truly is occurring rather than to come to some hasty and incorrect conclusions.

Is that a fair conjecture on my part?

Mr. TILFORD. I think for most aspects, that is a fair conjecture with few exceptions. I think one exception is the CFC issue. I think there that is considerable——

Mr. STENHOLM. There is agreement in that area?

Mr. TILFORD. I think there is agreement, at least among the people here at the table, that we all believe that something on an international basis has to be done there. I also think we all feel in terms of local pollution that there has to be a continuing effort in order to make sure that we do not increase the number of effluents because if we do we are going to have more tropospheric ozone and the impact on plants and animals is going to increase.

So there is a number of issues I think where we believe that it is time to look at policy issues. I think in the total aspect of global warming I am—personally I think it is premature to say that we know what to do.

I think we believe that, yes, based upon CO_2's and the other trace gases we will have an enhanced greenhouse effect. What the impact of an enhanced greenhouse effect is today with respect to growing seasons, precipitation patterns, I have no idea what the correct answer is.

Mr. STENHOLM. Would you agree with the statement that the greenhouse effect will cause an increase in average world temperature at a rate and magnitude unprecedented in human history? Do you have data that would validate this type of statement?

Mr. TILFORD. I think I would agree with that statement eventually, because if we were to continue to increase the amount of CO_2 and other trace gases in the atmosphere for an infinite period of time, physics and chemistry says yes, we are going to have a bigger, and bigger, and bigger greenhouse effect, and I do not know where the nonlineararities might take over, but today I can give you the results of the four best general circulation models in the world, I think, and I do not think there is an agreement at the 50-percent level, except—unless we do not put any more physics and chemistry into the model, and that is treating clouds as statistics, treating the ocean circulation as a box.

I mean we are almost to the point in trying to put in some of this stuff as putting in pure statistics. We have got to understand the feedback mechanisms to say whether it is positive or negative.

The whole CO_2 and the ocean issue that Alan Thomas brought up is one that requires a significant amount of more understanding as to what the deep ocean is contributing either in a positive or negative manner in terms of the total CO_2 problem, where the

equilibrium is and where the time scales are. We have a lot of unknowns that we have to go try to address.

Mr. BENTLEY. Mr. Chairman, could I just comment briefly?

Mr. BROWN. Dr. Bentley.

Mr. BENTLEY. I will try to summarize very quickly what I think about this question because what has been said is true, and I can only add to it.

One is that I look at the agricultural question as one of saying, can we put in motion today and in place today a system of getting information so that we could be at a better position to answer the question you have raised and it will probably be 5 or 10—and I cannot put a time on it. I will put 10 years on it as——

Mr. TILFORD. 20 is better.

Mr. BENTLEY. Pardon? 20 is better you said? Well, in other words, out to the future so that when we—when the country arrives at this point, well, we know for sure whether these changes are taking place as they relate to agriculture, because, as you know, that that will be one of the places where change in temperature, moisture, et cetera will be noticed, either hotter summers or longer period of hot weather, dry weather, and so forth are the things that happen.

And that is what we are wanting to do; to try to begin the system of research and adding to our research programs so that we can be in a better position to answer that question in the future.

I guess I am going to speak just a little bit now in a question that is sort of a parochial agricultural view. We have to be in agriculture we have to begin to appreciate that the urban build-up and the sources of air pollution that the urban problem of increase in NO_x or in other ozone or other periods that are more characteristic of population centers are also of concern of immediate interest of people in the rural area and the farming area. And for a long time we have had to argue, and I know personally of this, about when you raise this question, are we being an undue alarmist and not knowing for sure what is going to happen because somebody already remembers the 1930's and how dry and hot it was during that period of time, and says that that happens every so often.

So we have a bit of a parochial problem with regard to raising the level of sensitivity to global issues having to relate with food production, forest production, and water, and the availability of water. And that is part of what we are doing through our educational efforts as well.

Mr. THOMAS. Could I just make just one short comment on this?

Clearly, I would agree that we really do need a research program that starts to define much better, particularly, the regional effects of climate change because that is what will affect people, how they live and their economics, but in the interim I think we do need to work on an education program to make people sensitive to the global issues that we are facing.

Some of the factors that are going to be important, such as the deforestation in Brazil and the issue of further emissions, have not only greenhouse potential, but they are also part of some of the air-quality problems that we are facing on a more regional level. We need to develop the international mechanisms because we have to realize that these are global issues and they require a very broad

approach and this takes a long time. So that is why we need to start right away working on some of the international aspects, and maybe as a final area is that we know that cutting emissions would lower the potential for some greenhouse change in the future, and if there are policy alternatives that meet a number of goals that we have as a nation, then we ought to start analyzing the effects and find out whether—as we learn more about the climate, whether the benefits outweigh some of the costs.

Mr. BROWN. Thank you very much.

Thank you, Mr. Stenholm.

We are facing kind of a time problem here in that we have one more panel to hear from. Obviously the members of the Committee, both by their attendance and their questions, have indicated a very large interest in this. And I am not going to excuse you right at this moment because Mr. Roberts has some very penetrating questions about how to get more rainfall in Kansas. [Laughter.]

And that is very essential to our understanding of this problem, but I am going to ask the committee to try and bring this to a close, and we will ask you to respond in writing to any additional questions that we may have.

Mr. Roberts.

Mr. ROBERTS. Thank you, Mr. Chairman.

If the panel has any suggestions with regard to that specific problem, you can talk to me later and instruct me as to the kind of rain dance I must do. We tried one this weekend and it was not too successful.

Mr. Chairman, I would like to include in the record at this point an article from the Washington Post last January 8, by a Patrick J. Michaels, who is a professor of environmental sciences at the University of Virginia, and a member of the executive board of the American Association of State Climatologists. The article is entitled "The Greenhouse Climate of Fear". I do so to provide some balance to the hearing and Mr. Michaels has some rather pertinent things to say and I am sure some folks would think some controversial things to say, but I think in essence he is saying that we really do not know yet the extent of the global warming and why, and also has some concern about some policy debate that would force some social problems and economic problems on other folks all throughout the world, let alone this country, that might be a little rash, and that is an understatement.

So I would ask that this article be inserted at this point.

Mr. BROWN. Without objection, so ordered.

[The article follows:]

THE WASHINGTON POST SUNDAY, JANUARY 8, 1989 C3

OUTPOSTS

Every week in "Outposts," Outlook examines contemporary ideas that are changing our lives and expanding our intellectual frontiers. This week, Patrick J. Michaels looks at how concern over the greenhouse effect may be clouding our judgment. Michaels, a professor of environmental sciences at the University of Virginia, is a member of the executive board of the American Association of State Climatologists.

CLIMATOLOGY

The Greenhouse Climate of Fear

By Patrick Michaels

WARNING: Sen. Albert Gore has determined that the following article on global warming may be irresponsible. "That we face an ecological crisis without any precedent in historic times is no longer a matter of any dispute worthy of recognition," he told Time magazine recently. "And those who, for the purpose of maintaining balance in the debate, take the contrarian view that there is significant uncertainty about whether it's real are hurting our ability to respond."

What a strange sentiment. Scientific ideas stand on their own merits, not on the suppression of some facts and exaggeration of others. And Gore's statement is all the more disconcerting given his position on committees that oversee America's efforts in the environmental sciences.

There's no doubt, of course, that the senator's heart is in the right place. No one wants droughts, hurricanes and flooded cities. But attempting to squash one side of a scientific story is a treacherous business that can have only a negative outcome. As historian Thomas Kuhn has noted, major scientific advances tend to occur when a small group of researchers find problems with a widely accepted paradigm.

Moreover, none of us "contrarians" doubts that the greenhouse effect exists. If carbon dioxide and water didn't absorb the long-wave radiation emanating from the Earth, we wouldn't be here—the planet would be an ice ball. What we *are* saying is that the problem is more complicated and ambiguous than it seems, if only because we are putting more into the atmosphere than just CO2. In fact, of the hundred-odd scientists in the world actively involved in the study of long-term climate data, only one—James Hansen of NASA—has stated publicly that there is a "high degree of cause and effect" between current temperatures and human alteration of the atmosphere.

Apocalypse Now?

Here's what most observers think has happened to date: Northern Hemisphere temperatures rose about 1 degree Fahrenheit during the first 40 years of this century (before the trace-gas alterations were significant), fell for the next 40 years, and rose again in the '80s. How *much* is the subject of considerable debate. The fact that there has been no net warming since the 1930s is ascribed to the "flywheel" effect or thermal lag of the oceans.

Southern Hemisphere temperatures look a lot like what we would expect in Greenhouse World, except that the magnitude of the rise is about half of what it should be. Interestingly, that's the hemisphere that is 90 percent water. Even some of the greenhouse firebrands in the research community concede that the difference between the hemispheres—which keeps getting larger—casts serious doubt on our understanding of the entire problem.

Nonetheless, everybody, it appears, believes that the climate we have grown to know and love, D.C. snowstorms included, is coming to an end. And unless we do something about it we will witness a plethora of pestilence that will make biblical Egyptian plagues feel like a walk in the park. Those, incidentally, took place at the end of a relatively warm period, and one that often is cited as the nearest climate civilized man has seen to the one projected for 2020. (The computer-estimated range of average global warming from a doubling of CO2 is between 5 and 10 degrees Fahrenheit.)

Clearly, we have an issue that truly frightens most everybody (this author included), and that various groups see as an opportunity to save the world in their own image. That is not a situation that promotes objective knowledge. And that's what we desperately need as we begin making policies that, however laudably motivated, could cause real human suffering.

Consider, for example, legislation pending in the House (HR 5460) concerning U.S. involvement in the Third World. In order to fight the greenhouse effect, "priority shall be given to programs that enhance access of the poor to low-cost vehicles and efficient carrying devices, including access to credit for the purchase of bicycles, carts, pack animals and similarly affordable nonmotorized vehicles." This low-tech fix—favoring water buffalo over Hondas—accords nicely with everyone's favorite panacea: the planting of trees on "marginal land," which just happens to be where a billion of the world's poor live on subsistence agriculture.

Biologist Dan Janzen of the University of Pennsylvania, who holds the Crawfoord prize, the ecologist's equivalent of the Nobel, commented in a recent issue of Science that this was yet another example of forcing the poor to pay for the extravagances of the rich.

He's right. Interventionist policies of that sort will without a doubt harm people, at least via social unrest in the poor sorry countries that we force to fork over agricultural land in favor of fast-growing, if inedible, trees. "It seems clear," Janzen wrote, "that the tropics have already greatly exceeded their [population] carrying capacity for numbers of human beings with a reasonable standard of living." Obliging those folks to mitigate the effects of our pollution

"through a yet greater reduction of the carrying capacity of huge tropical areas does not seem to me to be a solution."

Especially not when so many questions remain unresolved. Here are a few recent revelations that somehow got lost with the ozone:

■ Last June, NASA's Hansen testified to the Senate that "1988 would be the warmest year on record unless there is a remarkable, improbable cooling in the remainder of the year." Even as he spoke, the tropical Pacific was cooling drastically. There's no way he could have known this, because his analysis didn't include temperatures for the sea surface, which covers 70 percent of the Earth. On Dec. 7 he recanted, calling the cooling of late 1988 "remarkable," even though a highly respected scientist with the National Oceanic and Atmospheric Administration counts 19 similar events in the last 102 years.

■ All summer, the dean of American climatologists, Jerome Namias at the Scripps Institution of Oceanography, had been saying there's no way one can scientifically defend any statement linking causation of last summer's drought to the greenhouse effect. Then in the Dec. 23 issue of Science, Kevin Trenberth of the National Center for Atmospheric Research and his coauthors convincingly argued that the drought of '88 was caused by warm ocean temperatures in the tropical Pacific, which have since dropped to near record low values.

■ Twentieth-century U.S. temperature data, which formed a part of NASA's congressional testimony last year, hide a drastic warm-measurement bias. NOAA scientist Tom Karl, who arguably knows more about regional climate variation than anyone in the world, has calculated that NASA's record over the United States has warmed up nearly a degree during this century mainly because cities tend to grow up around their weather stations, not because of the greenhouse effect.

If the effect of urbanization ("artificial" warming) on the temperature record averages the same over the rest of the world (and there's no reason to believe it doesn't), then there may have been *no* global warming to speak of during the last century. Karl's finding surprised none of us who daily toil with the data. But it should be a major shock to those who are using those figures for policy purposes. Is it irresponsible to point this out in public?

■ Similar problems surround the effect of ozone depletion, ostensibly caused by chlorofluorocarbons, another greenhouse gas. The amount of Ultraviolet-B radiation (the wavelength that causes skin cancer) is presumed to increase with ozone loss. Yet it has actually declined over the United States since meters were first put out in 1974. If everything were equal (it never is—you're older now and thus more likely to be afflicted) you'd find it harder to get skin cancer in 1989 than before the ozone hole was finally noticed.

Surprisingly, the Antarctic ozone depletion was three times less severe this past winter than it was in 1987. No proponents of the anthropo-generated ozone-depletion model and none of the computer simulations expected such a big change. The total concentration may indeed have been in the "natural" range that should occur there most every year.

If many of these findings are news to ordinary citizens, most policymakers know them all. Yet these findings either aren't being publicized, or they're being ignored as we march down the high road to change.

The Stubborn Air

Meanwhile, the uncertainties are manifold. The current CO2 count is about 350 parts per million. People used to think the background (the "natural" level before the industrial revolution) was about 295. Recent data from Antarctic ice cores put it at 260 to 280. New findings about the timing of the ice ages, however, calls our entire accepted model of climate change into question. The standard wisdom is that slight but predictable changes in the earth's orbital geometry induce a minor climate change that somehow alters the earth's carbon-cycle flow, resulting in a reduction in atmospheric CO2 and amplified cooling. But the latest data from the American west suggest that climate changes are thousands of years out of phase with Anarctic CO2 measurements, which are representative of global values.

At any rate, CO2's not the only thing going up. Consider the other thermally active trace gases: methane (partially from the bovine flatulence you've seen in the news lately), chlorofluorocarbons (thanks in part to the deodorant you used to use) and nitrogen oxides (you drive one of the sources). These gases all have thermal effects that can be expressed as if they were carbon dioxide. When those are added into the mix, you end up with an *effective* current CO2 concentration of 407 ppm. That's 150 percent of background—an amount that, if there were no oceanic thermal lag, should have driven up the globe's mean temperature about 4 degrees Fahrenheit between 1930 and 1985. That's enough to give even James Watt heatstroke.

But it didn't. And it has become pretty apparent that something—unknown and possibly creepy—has either prevented or delayed (we don't know which) the expected warming. Moreover, since Karl's findings show such bias in the temperature data, the Northern Hemisphere may actually have cooled off in the past 50 years. There are two alternative explanations: Either there's something that we're not factoring into the climate models ("unknown"), like all the other junk that goes in the air along

with CO_2, or it's going to warm up all at once ("creepy").

There's a modicum of evidence for both. One of the world's best temperature scientists recently published a paper that says that even the most liberal estimates of oceanic heat storage can't explain why it hasn't warmed up like it should have. One of our most politically conservative researchers, Hugh Elsaesser of Lawrence Livermore Laboratory, says that when it warms up it does so all at once. His evidence is the fact that most of the warming of the northern hemisphere this century was crammed into three years during Woodrow Wilson's presidency. Before and after, there's little change. The jury is still out on the 1980s, thanks in part to doubts engendered by the urban warming effect.

It is on that highly uncertain foundation that we are setting out to make development policy for the Third World. And if you think West Virginia's got problems now, come back after smoking coal becomes illegal. It's hard to understand how we can justify putting the coal miner's daughter on welfare or condemning Kinshasa to Addfare—particularly with forecasts that are mutually inconsistent. [See box.]

How to Stay Cool

What's a scientist to do? A little more candor from our media stars wouldn't hurt. In fact, most of us lesser beings emphasize the limnitations of our work everytime we get near a reporter. We should also urge science funding agencies to support more work on the temperature histories, even if subsequent findings may derail the policy express and injure the golden goose of Global Change.

What's a policy-maker to do? Some are taking advantage of uncertainty and public hysteria—the politics of fear—in order to promote sweeping actions that can result in major social problems far from our door.

Far preferable is to do something wholly unpopular given the current mood: Make plans, but do nothing that will injure human beings or increase poverty either here or abroad. Our policies should be no more drastic than the scientific conclusions they are based upon. And at present, the problems with the computer models and the temperature histories are simply too great. Instead, appropriate agencies should be channeling increased resources toward both those areas. Otherwise, we may very well be about to make a policy blunder of literally global proportions.

But what I fear is that all of the recent findings will be ignored. Policy—especially when promoted by very powerful special interests—has an inertia that is very difficult to overcome once the ball starts rolling, which it most certainly has. That makes all the hard work, all the science, inconsequential and irrelevant to those who say: Damn the data, full speed ahead!

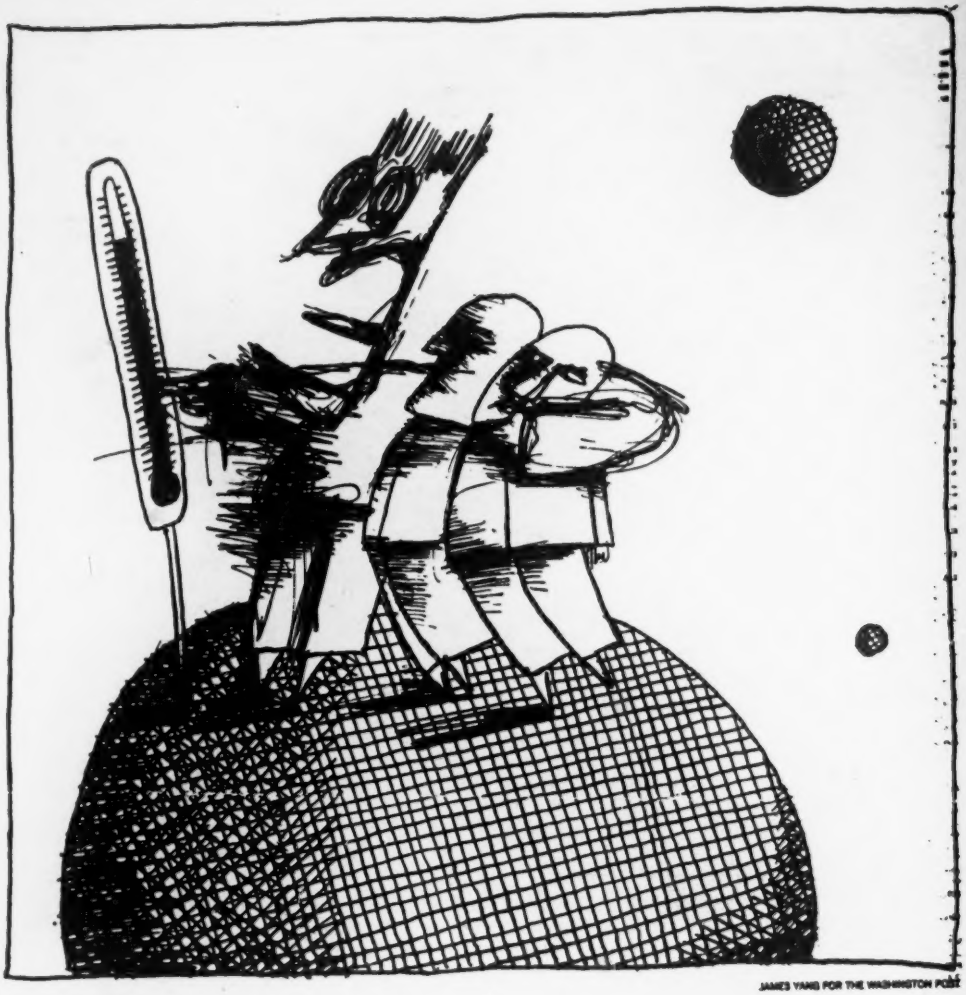
Computer Chaos

IF THINGS continue to go as they have, a doubling of carbon dioxide content in the atmosphere should cause a relatively minor temperature increase of between 2 and 4 degrees Fahrenheit. But when we feed the same data into the computers that run our climate-prediction models, Arctic warmings as great as 25 degrees appear. And global averages are as much as 10 degrees higher by the year 2030 than the computer says they were at background concentrations.

The problem is that these highly touted models are in fact research tools that are extremely limited in their applicability. Their physics isn't much different from the beast that produces the five-day weather forecast, something that people studiously ignore when planning the future. In fact, we shouldn't expect them to simulate regional climates very well, because they don't have the computational power even to include realistic ocean currents, which just happen to be responsible for most of the earth's heat redistributions (you call them "climates").

Is the state of the scientific art of hyper-long-range forecasting really this bad? Look at the Environmental Protection Agency's recent "draft" report (leaked everywhere—"no trees in Georgia" blurted Atlanta's Constitution). It used three of the main domestic climate models. Two of them predicted a major increase in July rainfall in Washington. The other predicted a big decrease. Given such differences, you might as well throw darts at a Ouija board while you tell the Third World what to do.

—Patrick Michaels



JAMES YANG FOR THE WASHINGTON POST

Mr. ROBERTS. I would just like to make a very quick observation. In my country at the coffee klatches, at the country elevators where all wisdom starts and all answers to problems are settled in about 5 minutes, we talk about the dry conditions that we are facing and we talk about what, I guess El Nino, and we talk about the greenhouse effect, and we talk about acid rain, and we talk about the deforestation, and we talk about—I personally think that the reason that it is so dry is because of the rock music that our Nation's kids listen to, more especially mine. [Laughter.]

I think there is a direct cause there, but at any rate, most of the old timers simply say we have been through a dry cycle in the 1930's. We have been through a very bad time in the early 1950's and it is our time now. And while I can appreciate the expertise that all three of you have provided, that seems to be the prevalent knowledge or the common knowledge at the coffee klatch shop in farm country, and as such, they are not particularly excited.

All of things that are designed to answer the problem of the global-warming situation are viewed with some degree of suspicion and concern, and my question to you is, which among you would like to comment on that? Is it time for the specific policymaking guidelines—I think it is time to discuss them, but I am not too sure that we need to be in the business of mandating them when all the facts are not in.

And which agency is going to do this? Is it going to be the USDA, Dr. Bentley, who is going to tell the farmer we are going back to the old T-standard of ASCS, if that is the question, on the conservation and compliance, or to tell the livestock producer, I am sorry, but we are going to put a cap on livestock production in this country because of the methane gas? Who is going to do that?

Mr. BENTLEY. I do not notice very many quick volunteers. I think the question is a very serious one about the perception. I think I referred to that in one of my remarks. There is a need to look at some of the issues that are taking place, in every one of them there are some problems that need to be looked at and I guess I come from a very middle of the road position that says we ought to look at some of the issues and the questions, and if we can resolve them now in a way that does not lead to perceptious change in practices as they apply to the community, whether it be in the Midwest where I come from or any other place in the United States or in the world, but for us not to be sensitive to some of the questions that are coming up.

We are having trouble with ground water problems. We are having some problems, but if we could identify those and take some steps, sometimes not very drastic ones that would help mediarate that question, I think that is where the leadership should be in reseach, and I hope that is what our research. And I think—I also say is why—an answer to Mr. Olin's question that we probably cannot go—or should be careful in evaluating scientific observations in terms of the practical application. That is a very difficult job that is going to involve not only the Government, but certainly the Congress and the private sector because that is where the so called rubber hits the road and we have to think this through very carefully, and that is what I hope we are trying to do in getting some of these trends and planning and determining the potential

impact and perhaps solution to those questions over the next decade or so.

Mr. ROBERTS. Well, the rubber has already hit the road in regard to various enviornmental issues, and we in agriculture have to do a better job of stepping up to that.

I guess, Mr. Chairman, I would simply agree with the next to last paragraph by Dr. Tilford in his excellent testimony when he says the CES research plant on all of which you are about will provide an important blueprint of how to improve our understanding. The key word here is understanding of the way in which the Earth's environmental—or pardon me—the environment varies naturally and in response to human activities, and then Dr. Tilford goes on to say, "This improved scientific understanding is critical to wise policymaking. It will fall to us to make the policymaking decisions", and I can tell you right now in farm country there is a reverse current building, if you will, on what kind of economic hardship this will be for them during a time that has been very rough in this past decade.

I do not want to get into an adversarial kind of situation here based on some scientific observation that is not complete.

With that, Mr. Chairman, I yield back, and thank you, sir.

Mr. BROWN. All right. Any of the other members who have not asked questions desire to interject a short question at this point?

[No response.]

Mr. BROWN. They have obviously taken the chairman's hint very seriously.

Thank you very much, gentlemen. Let me make one concluding observation. Obviously the committee is concerned that we not be stampeded into precipitous policy action in this field. That has been reflected in a number of us, and I think one of the purposes of this hearing is to create the fundamental understanding of the current level scientific knowledge that we will not be stampeded despite flamboyant articles that may appear and so forth.

On the other had, what we obviously also perceive is the need to improve understanding of the scientific facts. I know, for example, just reflecting on some of the testimony here, more than 10 years ago NOAA was presenting the situation that they did not fully understand the effects of the ocean on the uptake of carbon in the atmosphere. They still do not understand it.

The problem is they have not been provided with the resources to move as rapidly in this area as they need; like wise, the issue of separating assessment from policy, very important, very frequently are—we conjoin the two and we come up with lousy assessments and lousy policy both.

That was an issue with EPA 15 years ago, as I recall, when they were taking environmental risk assessment, enviornmental policy and mixing them together and you got a hodge bodge and we still do not have that problem solved.

What is obviously necessary is we have a coherent, integrated, fully thought out research strategy, obviously it needs to be global in this connection, so that we can produce at an increasing pace the assessment information, the scientific information on which we can begin to make policy, and it will take place incrementally.

We will be able to make a little policy here and a little policy there. It will be a long time before we can make the total policy that we need.

We hope this hearing will contribute to an understanding of these kinds of things and will allow us to act more rationally in the future. And you have made a great contribution of that.

We may submit some questions to you in writing. If you will kindly cooperate with us, we will appreciate it in order to fill out the record.

Thank you very much.

Mr. BENTLEY. Thank you.

Mr. BROWN. Our next panel, Dr. Boyd Strain from Duke University, Dr. Pierre Crosson, Resources for the Future, Mr. Justin Ward, NRDC, and Ms. Cynthia Rosenzweig from Columbia University and NASA/Goddard.

We are pleased that you would be here with us to contribute to our better understanding of this problem. Each of you has a unique point of view on the subject, and we apologize for not getting to you a little more quickly. And I know some of you have time constraints. So would you proceed, Dr. Strain, with your testimony.

I think if you can limit it to possibly 5 minutes and summarize your written statement. The full text will be put in the record, of course.

STATEMENT OF BOYD R. STRAIN, PROFESSOR OF BOTANY, DUKE UNIVERSITY

Mr. STRAIN. Thank you, Mr. Chairman.

Thank you for inviting me here, and I will make my oral statements very brief. My written testimony has been filed, and I would hope that that could be included in its entirety in the record.

Mr. BROWN. It will be, Dr. Strain.

Dr. STRAIN. In addition, I have made one clarifying statement that I would like to add as an addendum to that statement, if you could, please.

This addendum is a published paper which I think may explain some of the aspects of my testimony and make them more clear.

I think it very critical that we carefully define this problem. The title of this hearing is "Climate Change and Agriculture." All of our previous speakers have mentioned, and much of the testimony has been about, environmental factors that are not the traditional climate factors. We all think of temperature, rain, and maybe periodicity of events when we think of climate.

We are, however, dealing with total environmental change; global environmental change of many factors. One of the drivers here is carbon dioxide, an environmental factor which has never been included as one of the climate factors. So we do have to broaden our thinking to global environmental change and to consider all of the factors.

I think if we initiate a significant research program of climate change only, the next decade will find a new environmental problem for us, and we will find that our research program was short. So we do need to recognize at the beginning that we are dealing with multiple factors and we have to take a basic research ap-

proach to understanding each of these factors. Then, perhaps more importantly, we need to learn how they interact with each other.

We must realize that organisms (that is plants, animals, and bacteria) all respond to all environmental factors; temperature, toxic gases, water, and UV-B radiation. The biological system of the Earth is a result of how each organism responds to the basic environment, and then how the organisms in turn respond to each other. So if we have a changing environmental condition that seriously affects one type of species in the world, it is likely that other species will also respond.

So the ecological interactions have to be known, learned, and incorporated into our attempts to predict future biological response to future environmental conditions.

The known plant responses are many. My laboratory has edited two large volumes in the last 2 or 3 years on plant responses, and those have been provided to Mr. Myers of the staff. They could be drawn from, summarized in some way into the record if they are needed to get a more complete understanding of plant responses to CO_2 and to other environmental change factors.

Relative to an appropriate research approach, I agree with previous speakers that we need to take a modeling approach. We also have to have basic understanding, however, to put into those models and to have actual data to run in them. I think we have to take a modeling approach but it must be based on facts and hard data.

We also have to find a way to validate our predictions of those models. We have to have ways to conduct validation experiments. If we are going to make a prediction 10 years from now about the biological or agricultural responses to occur 50 years from now, we should have some way to validate the predictions that our model is making.

We are conducting an experiment now which is a DOE/USDA joint experiment. It ran for 3 years in Mississippi, and now it is being moved to Arizona to be repeated under a quite different condition. It is a free air release of CO_2 with some other manipulations going on in parallel. That is an attempt to collect information which could be used to validate the models that we have been building for the climate change CO_2 effect.

One other technique is just now being designed. It has not been applied yet, but it is the concept of a macrocosm or a large totally controlled greenhouse facility which could be put over an agricultural field or over an ecosystem. In these devices we can control the gases in the air and other environmental factors as well. One of our problems in research in this area is we have not been able to control the atmospheric gases.

In my written testimony I mentioned several uncertainties. I think in the interest of time I will not comment specifically on those, and we can discuss them later if there is time.

[The prepared statement of Mr. Strain appears at the conclusion of the hearing.]

Mr. BROWN. Thank you, Dr. Strain.

Dr. Crosson.

STATEMENT OF PIERRE CROSSON, SENIOR FELLOW, RESOURCES FOR THE FUTURE

Mr. CROSSON. Thank you, Mr. Chairman.

I too would like my written statement to be made part of the record.

Mr. BROWN. It will be.

Mr. CROSSON. I am going to talk about problems of adaptation and adjustment in agriculture as a result of climate change.

Let me at the outset say that I think it is important to make clear what amount of climate change we are talking about.

Most of the work that has been done in this area looks at the consequences of the equivalent doubling of CO_2 in the atmosphere, but a point was made by our previous panelist that so long as the emissions of greenhouse gases exceed the capacity of terrestial and oceanic sinks to absorb them, they will continue to accumulate in the atmosphere and warming could go well beyond that associated with 2 times CO_2.

I say this because my remarks relate to the consequences of 2 times CO_2 warming. I would no doubt come to different conclusions if I looked at the consequences of warming beyond that amount.

One of the problems in getting at the question of how agriculture might adjust to climate change is the inability of the climate models to distinguish among regions as to what the consequences of global warming will be for regional climates.

It is clear, however, that there will be significant regional shifts in comparative advantage in agriculture. The evidence that we now have, fragmentary though it may be, indicates that some regions in some countries around the world likely will benefit from the amount of warming associated with a doubling of CO_2. Other regions are going to be worse off.

It is not clear at this point that on balance the effects of that amount of warming on global agricultural capacity will be negative. There is reason to believe, and some studies suggest this, although nothing is conclusive at this point, but there is reason to believe that the countries which gain from—or the regions which gain from that amount of global warming may roughly offset those that lose.

But the important point is that even those regions which may gain from climate change still will face problems of adjustment in order to take advantage of whatever benefits climate change may bestow on them.

But the main concerns are with those regions which are likely to be disadvantaged by climate change, and at Resources for the Future we think it is useful to think about the adjustment problems in terms of short-term adjustment possibilities and then longer-term adjustment possibilities.

The short-term adjustment possibilities are those that farmers can make within the existing technical and managerial regime that they operate under. For example, there is some work that was done by people at the International Institute for Applied Systems Analysis in Austria indicating that in the Canadian prairie areas are likely to become warmer, that the possibility of shifting from Spring wheat to Winter wheat with existing varieties offers possi-

bilities of making a favorable adjustment to the climate change under those circumstances. Well, that is just an example, but there are many others that could be adduced.

Over the longer term, the issue is the development of new technologies and new management procedures or practices which are better adapted to the changing climate regime, and we believe that increased investment in research to develop new crop varieties, which are better adapted to those changing environments, is a major example of what we have in mind when we refer to long-term adjustment possibilities.

Norman Rosenberg, now at Resources for the Future, did some work some years ago showing the spread of production of Hard Red Winter wheat in the Great Plains since 1920 across temperature gradients which are even greater than those that are now being projected with a doubling of CO_2.

So we think there is a major potential for long-term adjustments through increased investment in research to develop more favorable technologies.

Let me say in closing that we see three major strategic policy choices for disadvantaged countries, countries that are disadvantaged in their agriculture as a result of climate change.

One is to seek these various adjustments that I just referred to as a way of offsetting at least some of the unfavorable impact of climate change.

Another possibility in those countries is to simply take their losses after doing what they think they can do to offset these damages and rely on the international trading system as a way of meeting or offsetting the disadvantages to agriculture that climate change imposes on them.

Finally, these countries that are disadvantaged may in fact resist the consequences of climate change by resorting to protectionism of various sorts, raising tariff or other trade barriers against imports of agricultural commodities. That clearly is a possibility. We think that would not be a fruitful way to go, but it is one of the strategic choices that will confront countries as they attempt to deal with this problem.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Crosson appears at the conclusion of the hearing.]

Mr. BROWN. Mr. Ward.

STATEMENT OF JUSTIN R. WARD, SENIOR PROJECT ASSOCIATE, NATIONAL RESOURCES DEFENSE COUNCIL

Mr. WARD. Thank you, Mr. Chairman. I appreciate the opportunity to testify.

We are pleased that the committee is focusing attention on the agriculture and forestry dimensions of global warming. We have furnished a detailed statement for the record, and I would be happy to answer questions on the issues raised in our submission.

We have also recently published a report which is entitled, "Farming in the Greenhouse," which is also submitted for the record.

In my brief remarks today I would like to respond semicritically to a column in Saturday's Washington Post by Dr. Crosson and colleagues at Resources for the Future.

Their editorial and to some extent the testimony given today I believe helps frame the issue of world food security under a changing climate.

In the first place, let me say that I agree with the RFF's bottom line conclusion, which is that faulty distribution systems are at the present time the crux of the world's food problems.

I also think that the recommendations with respect to developing adaptive responses to climate change in Dr. Crosson's testimony today makes good sense.

When it comes to natural resources and long-range agricultural productivity, however, we take a somewhat less optimistic view.

Let us examine then the RFF's principal assertions. First, the authors stated categorically that the 1988 drought is not evidence that droughts are becoming more frequent.

One must, of course, hope that this is the case, because if the 1988 experience begins to repeat itself more regularly, especially in sequences of two or more consecutive years, agriculture will face difficult times indeed.

The RFF analysts' unqualified claim suggests in this case that perhaps the economists have learned something as yet unknown to the climatologists.

We think it is worth paying attention to the projections from NASA's climate models, which have shown that the probability of drought in the United States will be 60 percent in the 1990's, nearly twice the probability from the period 1950 through 1979.

James Hansen, the Director of NASA's Goddard Institute has stated that these are hard predictions which will be tested in the next decade.

The RFF economists are quite correct in pointing out that scientists are uncertain about how global warming will affect agriculture. This too is a central thrust of our written testimony.

They proceed to state flatly, however, that crops can be adapted to severe change in climate, and carbon dioxide by itself has a favorable effect on plant growth and may offset plant stresses causes by climate warming.

This is plain wish fulfillment, which echoes a familiar refrain from USDA's Climate Impact Research Program. In point of fact, modern agronomy has produced miracles, but there are definite limits to what crop breeding can accomplish, especially in the area of drought resistance.

Given the long times required for development of new plant varieties, this has to be regarded as a limited adaptive strategy, especially if the warming trend occurs faster than expected.

As for the claimed benefits from CO_2 fertilization, it is a quantum leap to extrapolate from findings of crop growth enhancement in laboratory settings to the real world. The experimental results should be accompanied by a lot more qualifiers than USDA researchers have offered to date.

This issue is addressed at some length in our written submission, and basically we find that the current USDA Climate Research Program is one dimensional and misdirected. We have recommend-

ed a more systems-based approach that seeks answers to how we might reduce emissions of carbon dioxide, methane, and nitrous oxide from agricultural and forest resources, as well as better understanding of how our farming and forest systems will be affected by climate change, particularly under scenarios of more frequent heatwaves and droughts. I must say in this regard that I am encouraged by portions of Dr. Bentley's testimony this morning that suggested the Department appears to be moving more in the direction of the inter-disciplinary program that we believe is needed.

To further dispel concerns over food security, the RFF authors note that world food production has been rising steadily in recent decades, and this is correct.

Specifically, the article points to a near tripling of grain production for 1950 through 1987, mainly from increased per acre yields, rather than an expansion of cultivated area.

The rest of the story that should be told is that much of the increase in productivity can be traced to parallel increases and applications of yield-enhancing pesticides and fertilizers. In fact, farm chemical use in the United States, the world's leading agricultural nation, has grown nearly six fold since 1950.

This trend has, of course, not been without a substantial price to ground water quality and other environmental values. It has also had a major impact on farmers' production costs.

Finally, the RFF column suggests that we have adequate agricultural land resources to satisfy all crop production needs for now and into the foreseeable future. They note that this Nation has some 150 million acres of pasture, range, and woodland with high to medium potential for conversion to crop land.

What the article overlooks is that nearly two-thirds of this potential crop land is rated by SCS's land capability class system as being in class III or above. By SCS's reckoning, such lands are either totally unsuited for sustained long-term crop production, or have serious limitations that make conservation practices very difficult to apply and maintain.

A further point discussed in our written statement is that breaking out new pasture or leveling standing forests to enable crop production results in significant carbon emissions, thereby feeding the greenhouse effect.

In conclusion, our purpose here is not to paint a doomsday scenario; nevertheless, we find little to recommend what can be termed the "Don't worry, be happy" doctrine as it pertains to agriculture and forestry in a changing climate.

Certainly not all the facts are in, and our crystal balls will never be totally transparent. There is significant indication, however, that catostrophic consequences are at least within the realm of possibility.

Therefore, we believe that in the face of all the uncertainty, the conservative route is the one to pursue.

Thank you very much.

[The prepared statement of Mr. Ward appears at the conclusion of the hearing.]

Mr. BROWN. Thank you, Mr. Ward.

Ms. Rosenzweig.

STATEMENT OF CYNTHIA E. ROSENZWEIG, DEPARTMENT OF GEOGRAPHY, COLUMBIA UNIVERSITY AND NASA/GODDARD INSTITUTE FOR SPACE STUDIES

Ms. ROSENZWEIG. Thank you, Mr. Chairman.

Mr. Chairman and members of the Committee, for the past 2 years I have served as the coordinator of an integrated set of studies on climate change and U.S. Agriculture.

These studies were part of the U.S. Environmental Protection Agency's report to Congress on "The Potential Effects of Global Climate Change on the United States."

The studies were carried out by scientists at agricultural research universities and Federal and State agencies in the areas of climate change impacts on corn, soybean and wheat yields, regional and national agricultural economics, irrigation, water quality, agricultural pests, farm level decisionmaking, and livestock diseases.

The entire EPA report is currently in draft form and is undergoing comprehensive, scientific, and interagency review.

Given the current projections of global climate change, the main conclusions that may be drawn from the EPA studies are: First, significant regional shifts in agricultural production are likely.

Our study showed that agricultural production of grain crops may shift northward. All of the climate change scenarios tested show that the southern areas of the United States become less productive relative to northern areas. I would also like to point out that this study considered agricultural land only.

Second, impacts on U.S. production could affect global food trade. In three out of the four scenarios that we tested, export levels declined.

Now it is important to note at this point that climate change may expand or limit agricultural production, as some of the other speakers have mentioned, in other areas of the world, and that the patterns of global food trade may change, affecting the role of the United States as an exporter.

Third, climate change could exacerbate many current trends in agricultural pollution and resource use. For example, farmers are likely to demand more water for irrigation since crops need more water when it is hotter. Also, irrigated yields are more stable year to year.

An increase in demand for irrigation by farmers could place additional stress on water systems which are already overdrawn such as the Ogallala Aquifer in the Great Plains, and this could heighten societal conflicts over water.

Also, if agricultural zones shift around the country and because agriculture is not necessarily a benign influence on the environment, climate change may bring increased soil erosion, ground and surface water pollution, and loss of wildlife habitats to regions where they do not currently occur.

Uncertainties must be raised at this point. One of the main uncertainties is: if droughts occur more frequently under changed climate (and this is a current research issue on the climate side) the effects on agriculture may be more severe than the ones that I just listed.

Also uncertain are the magnitude and rate of change of warming, as well as the future directions of technological change in agriculture in the coming century.

Besides being a recipient of the climate change impacts, agriculture itself is an active contributor to the greenhouse effect through emissions of the greenhouse gases.

It is estimated that 10 to 30 percent of the CO_2 emissions come from agriculture from clearing of trees and shrubs. As for methane, perhaps 30 to 50 percent of the methane emissions come from ruminants (cows and sheep) and also flooded rice paddies. About 10 percent of nitrous oxide, which is another greenhouse gas, may come from fertilizer applications.

The EPA studies provide an initial assessment of climate change in U.S. agriculture. Much work remains to be done. Finding effective ways to reduce the emissions that I just mentioned presents a major challenge to the agricultural research community.

A strong research effort must be maintained and expanded in order to ensure technological improvements in agriculture and to limit vulnerability to climate change.

Especially important is the continued development of heat and drought tolerant crops, and alternative crops. Biotechnology may be able to contribute to these efforts.

Also needed is interdisciplinary research on changes in rural communities. If agriculture goes down in some areas and changes and increases in others, this will affect the people and the agricultural infrastructure in those areas. So rural sociologists and economists need to look at these issues.

Another crucial area is the projection of climate change effects at the international level and the consequences to U.S. trade.

Given the large uncertainties surrounding future climate change, policies have to make sense for today.

Flexibility in adjusting to potential climate change should be a policy goal. Inclusion of potential climate change in land-use planning and water-resource management, and ensuring sustainable use of agricultural land are warranted.

Improved risk management and drought policy should be implemented, as has been amply demonstrated by the events of and the responses to the drought of 1988.

Also, relevant policy makers need to consider the implications of the potential long-term changes in levels of U.S. crop exports.

These policies that I just mentioned are adaptation policies. I also believe that the policymakers should consider preventative policies about the climate change issue.

It is well understood that increased trace gases will eventually cause global warming, and that trace gases are increasing. A certain amount of trace gases have already been put into the atmosphere, and the scientists assure us that this will cause a certain level of warming.

We may not be able to prevent climate change completely, but we may be able to limit climate change through examination of such things as increases in energy efficiency and decreases in tropical deforestation.

The companion report of the Environmental Protection Agency to the Effects of Global Climate Change Report deals with the potential options for stabilizing global climate.

In conclusion, the initial EPA analysis of the impacts of climate change on U.S. agriculture indicates that concern about climate change is amply justified.

This is especially true when considering agriculture in the broadest sense as a primary user of the Nation's land and water, a network of productive rural communities, a strong and not often benign actor on the environment, a renewable resource base that provides industrial and domestic products beyond food and fiber, and a reliable supplier of agricultural export commodities.

Thank you.

[The prepared statement of Ms. Rosenzweig appears at the conclusion of the hearing.]

Mr. BROWN. Thank you very much, Ms. Rosenzweig.

Your report may have covered all the grounds that we wanted to cover in this hearing, and in much more detail. Do you have a date that you expect to have that submitted to EPA?

Ms. ROSENZWEIG. The final version of the entire EPA report, which deals with impacts of climate change on many areas besides agriculture—for example, forestry, human health, and biodiversity—is due out in the summer months of this year.

Mr. BROWN. The summer months.

Ms. ROSENZWEIG. Yes.

Mr. BROWN. I guess we can wait that long. Mr. Roberts.

Mr. ROBERTS. Yes. Thank you, Mr. Chairman, and I want to thank all the members of the panel for taking your time to come before us.

I think I am going to try to concentrate my questions in regard to the testimony offered by Mr. Ward of the NRDC, and that in reading his testimony, I think it pertains to my earlier question of the previous panel in regards to the policy decisions that may or may not be forth coming as we continue to monitor the global warming situation, and I would add only that since Mr. Ward is a senior project associate—oh, and by the way, Dr. Crosson, if you would like to offer for the record a response to Mr. Ward, I do not think we are setting a precedent for the Lincoln-Douglas debates, but in the interest of fairness, I think if you would like to offer a response for the record, that would be fine.

Mr. CROSSON. Shall I do that now, or——

Mr. ROBERTS. Because of the time constraints, why do you not do that in writing, if that would be all right with the chairman.

Mr. CROSSON. All right.

Mr. ROBERTS. But it is my time now.

Mr. CROSSON. Right.

Mr. ROBERTS. The question I have is not so much that we in farm country are singing the tune, "Don't Worry, Be Happy," but we are terribly concerned and very sober, I think, in our reflections on what we will be facing us down the road.

After all, it is our ground water, our crops, our families, our wherewithal, our livelihood, and in that regard, I would like to go down through your testimony to some degree in regard to some of the specific recommendations, because you have, in fact, taken

these problems head on to the extent you are recommending some specifics, as opposed to some witnesses whether we have that, say on one hand, but on the other hand.

So you have a rather one handed testimony here, and I want to thank you for recognizing the problem we have out on the High Plains in regard to the moisture situation and the possibility of serious dislocation.

You listed on, I think, page 10—if you want to turn to that in your testimony—about 5 or 6 alternatives. One, right off the bat, the greenhouse gas emissions from ag sources, you are talking about the possible adjustments in dietary patterns that enabled reduced beef production, holds significant promise for abatement of methane production and reduced deforestation.

How would you do that? What do you have in mind, specifically?

Mr. WARD. Mr. Roberts, I do not mean to suggest here that we begin to have all the answers on this. It is clear that the methane question is one of the least tractable of the greenhouse gas situations, and it is not at all apparent just how we should undertake to abate emissions from agricultural sources.

Suggesting that adjustments in dietary patterns may be one way to do this, involving reduced beef consumption, and hence, less livestock grazing and associated deforestation internationally to enable expanded beef production is simply one avenue that I offer by way of example.

Mr. ROBERTS. Well, let us go down that avenue. Who would make that recommendation in regard to dietary guidelines that would lead to reduced—beef production?

I might add the Kansas Livestock Association is in town. I am having lunch with them at 12:15, and I think they would be very interested in that.

Mr. WARD. My recommendation is that it be one of the things that USDA looks at as part of its Comprehensive Research Program.

Mr. ROBERTS. And after looking at it, it would be a recommendation then that they would come up with guidelines? What?—per person, or would it be in relation to the global warming threat on a percentage basis, or are you going to put a cap on livestock production in the country, or a certain size limitation on a herd? What are we talking about?

Mr. WARD. I have not reached that, but it is a recommendation for further research in this area, and I suspect that the outcome of that would determine what the policy prescription might be.

Mr. ROBERTS. So this is pending further research?

Mr. WARD. Correct.

Mr. ROBERTS. And not a specific guideline recommendation, or a policy recommendation that you would like the USDA to tell our cowboys specifically, because of the global warming, we ought to recommend to Americans to eat less beef.

Mr. WARD. I have not recommended that.

Mr. ROBERTS. So we are doing the backstroke a little bit on that one. We are treading water with that.

Mr. WARD. Yes.

Mr. BROWN. Ms. Rosenzweig would like to interject and comment.

Ms. ROSENZWEIG. I would just like to comment. I think Mr. Bentley was also asked about research in this area about the potential decrease of methane emissions.

There is on-going research at USDA in Beltsville on the efficiency of feed conversion in cattle. If the cattle are more efficient with their feed, you get increased weight gain and decreased methane emissions. That is an exact example of a research direction, which makes sense for both cases—both for the greenhouse effect and also for the producers.

Mr. ROBERTS. I thank you for your contribution. I think Mr. Stenholm will have something to say about that on down the road.

Let us go to No. 2, since we are now treading water and not stroking boldly in an area where I think there might be some problems for the ag committee, not to mention the livestock industry, which is pretty hard-hit out in my country with the drought.

We have a statement that you would like to go to the development of alternative crop varieties and protection of biotic diversity.

Mr. Stenholm and I have an acreage base substitution plan that we have been working on for some time to allow farmers to go to alternate crops, and we would certainly welcome the NRDC's strong interest in that area.

We are not going to move to those kinds of things unless we get some acreage base flexibility, because the producer is locked into that situation from an economic standpoint. Are you aware of that, or would you be in favor of that approach?

Mr. WARD. I am not aware of that specific proposal, but we do have a strong interest in that area, and as a general matter, would support efforts to provide the kind of flexibility within base acres and other aspects of the farm programs that would enable those kinds of alternatives to be developed.

Mr. ROBERTS. Mr. Stenholm and I would welcome you to step forward in that, you know, homework phase of that particular plan, because we are not going to get there from here unless we achieve some progress.

Three, you are talking about an innergovernmental analysis of linkages between agriculture production and global climate change as expanded research project under the Ag Productivity Act, designed to increase fixation of nitrogen and carbon on farms, and to enable farmers to reduce their reliance on fossil fuel inputs. How are we going to do that?

What are we talking about here—no further use of nitrogen, i.e., fertilizer, and the farmer is going to have to reduce his reliance on fossil fuel inputs, diesel gasoline, et cetera, et cetera. What did you have in mind there?

Mr. WARD. What I had in mind is a research program that is intended to confer ultimately, both an economic benefit on farmers' production costs, as well as environmental payoff.

I am talking about a research program that is in progress now, namely the Low Input Sustainable Agriculture or "LISA" Program.

Mr. ROBERTS. Oh, yes, "LISA".

Mr. WARD. What H.R. 1078, the Scheider bill, would authorize expansion of that effort, with a greater emphasis on aspects of that may benefit a greenhouse abatement.

Mr. ROBERTS. But you are not talking about mandates in regard to restrictions in regard to fertilizer, et cetera, et cetera, or are you?

Mr. WARD. This is, at present, a competitive grants program administered primarily by CSRS. It is essentially an applied research program, one whose mission is to develop practical alternative farming approaches that have some immediate relevance to——

Mr. ROBERTS. I think the chairman and all members of this subcommittee are very familiar with the LISA proposal and the plan, and as a matter of fact, I am going to be introducing a food safety bill here in the near future that ties into that and integrated pest management, and the need to step up to that as best we can.

On page 11, you were talking about the recommendations by Mr. Moomaw indicating the USDA should prepare a long-term plan for adapting U.S. agriculture and forestry policies, potential consequences of climate change, and the possible shifts in production zones, and to prepare for a large increase in forest fires. You also go ahead about more systematic drought planning.

I am not familiar with the recommendation by Don Wilhite from the University of Nebraska. What is that?

Mr. WARD. I do not know all the details. I heard him speak last week at a conference sponsored by the Environment and Energy Study Institute and World Resources Institute. His argument was basically that we do not have a drought planning mechanism currently. Only a handful of States have developed them and with limited success. The Federal Government has not implemented a mechanism for this purpose.

He suggested, in particular, that the time to develop coherent drought planning programs is during wet years, but we never do that. It always occurs in kind of a crisis mode, when we are suffering from severe moisture shortages and hot weather. That was the essence of his talk.

Mr. ROBERTS. When you say "drought planning," are you talking about specific assistance to producers, or are you talking about what? I am not sure what you—you see, at the present, we brought the Secretary of Agriculture to Kansas for a first-hand look at the situation out on the High Plains, and I am pushing a disaster assistance bill that is crops specific. I worry about the budget implications. I worry about what that would do to our crop insurance policy.

We are trying to say, "Let's don't have a disaster bill every third foggy night, or when we have an election around here," which seems to be the case. "But let's move to crop insurance," but crop insurance does not work well out in the High Plains.

So we have not had a lot of—well, we have had a rather dramatic increase, because of the dryness of the year, but are you talking about assistance to producers to overcome the economic hardship, or what?

Mr. WARD. I think that that would be one component. Other areas that would probably be part of a comprehensive plan would include planning for planting decisions and timing, types of crops raised, irrigation, things such as that.

But yes, I believe that——

Mr. ROBERTS. Information that the producer could use to withstand a cycle that would be forthcoming as predicted by our so-called experts?

Mr. WARD. Yes, as well as advance planning in effect for the nature of Government assistance to be given to farmers.

Mr. ROBERTS. There is a specter here that some have discussed that the USDA should be in the business of predicting where production zones should be, and designing farm programs so that it would be helpful to those production zones as opposed to your traditional growing areas. Are you into that business? Are you recommending anything like that?

Mr. WARD. No.

Mr. ROBERTS. Good. The one concern I have here on—and I will label No. 5 at the bottom of page 11 "climate change should likewise be integral to the soil and water assessment programs developed by USDA's Soil Conservation Service, and we have questionable judgments on the adequacy of natural resources for future food supplies and the protection of the rural environment."

I am just going to make an observation. Let me ask you a question. You folks have been shining the light of truth into darkness in the pesticide issue with your selective flashlight, and it occurs to me that if we go back to the 1930's and 1940's to produce the harvest, and—in other words, if LISA lives, and we go to that as best we can, and we go back to the 1930's and 1940's in regard to the harvest of 1985, you would have to convert 60 to 75 percent of the forest land and crop land to production, which we do not want to do.

And then on the other hand, we are talking about a change in the climate where we simply cannot do this—that we have to conserve more crop land. How do you justify that? If the farmer cannot use the commonly used farm chemicals that we use, even those that are undergoing scientific review, and I am not going to get in the alar situation—oh, I might, but I do not think I will do it as of this time period.

But how can we justify that? It would seem to me you are working at cross purposes here.

Mr. BROWN. Before you answer that question, Mr. Ward, I want to excuse Dr. Strain, who has an airplane to catch, with my thanks for his being here this morning. I did have other questions for you. I may send them to you in writing, Dr. Strain.

Mr. STRAIN. Thank you, Mr. Chairman.

Mr. BROWN. You may proceed.

Mr. ROBERTS. Thank you, Mr. Chairman.

Mr. WARD. You started out asking about a recommendation——

Mr. ROBERTS. Let me make it shorter, and I apologize to the chairman and my colleagues for carrying this on, but I think it is a very important question.

We have a situation here now, where we want to go to low input sustainable agriculture. We want to go to integrated pest management as best we can. We want to make sure that the scientific review process works with the alleged bad actors of the some 300 commonly used chemicals that we use out there, and the NRDC has been very active in alerting the American public to the possible dangers, and my point is, if you go back to Walden Pond agri-

culture—that is my word, not yours, and I am using it not as a pejorative, but something to describe a way of farming—you are going to have to put about 60 to 75 percent more crop land back into production—the very forest and the very prairie lands that you are saying we need to increase.

It seems to me that we are at a juxtaposition here. You know, we are at odds with each other. Would you care to comment about that?

Mr. WARD. Well, I cannot comment on the estimate you gave. I mean, the point you seem to be making is that, by virtue of a transition to low-input systems, that would necessitate an "extensification," if you will, of our crop land base.

Mr. ROBERTS. Well, if we are to maintain current production levels, I will not say that these estimates are written in stone in regard to being accurate, but obviously, we would have to increase production right at the same time when you are advocating, because of the global-warming situation that we cannot do that. And I just think it ought to be obvious that one policy recommendation does affect the other, and I do not mean to overstate the case.

Let me ask one other thing here.

Mr. WARD. Let me respond. I would agree that the two are related, and to tell the truth, I have not pondered to a great extent the interconnections. We do, in fact, support policy adjustments that would favor, rather than penalize as the current system tends to do, low-input alternatives. We do not necessarily regard those as the road to reduced per acre yield reduction over the long run, and we would hope that systems could be developed that enable current levels of production with reduced use of pesticides and fertilizers.

I think there is evidence to that effect. I mean, certainly on the fertilizer side of things, there is strong evidence that our current application rates are inefficient, that we could get comparable yields with less inputs——

Mr. ROBERTS. We could always do better, I am sure, but in our obligation to feed this country and a very troubled and hungry world, something has to give in the area of common sense and actual farming practices.

You have—and this will be the last, Mr. Chairman—a recommendation on page 13 to the conservation compliance section of the farm bill that the SCS is, "routinely developing alternative conservation systems that fail to prevent productivity threatening rates of soil erosion."

John, was it last summer or the summer before in our 58 county tour, when the SCS thing hit us right in the face.

It was the summer before last, once we passed the farm bill and the conservation compliance, the No. 1 issue at the country elevator, and my 2,700 mile tour involving 58 counties, which you are welcome to join. As a matter of fact, I would like to have you with me. It would be an interesting thing, I think, for the both of us.

But at any rate, the No. 1 question is—What on Earth is SCS doing, trying to dictate to me farming practices which make absolutely no sense out on the High Plains and costing me anywhere from $555 per acre on down? And that is when members of this subcommittee and others talked to Mr. Wilson Scaling of SCS and

asked him to at least allow commonly used farming practices that were an accepted conservation practice.

It seems to me here that you want to go back to the old T-standard and say that we are going to be very strict. As a matter of fact, I still do not have authority for a farmer to rotate his alfalfa production. Then he is in violation of sodbuster, and we still do not have any legal authority to do that.

If you cannot do that, it seems to me you are really infringing upon a good conservation practice and a normal cropping procedure. We have to work together in this regard, and I have a little problem here in regard to going back to that strict interpretation of conservation compliance.

I thought we had been doing a pretty good job in that respect of educating and alerting the farmer to that responsibility, but I do not want to go back to the very strict interpretation that you are advocating. Would you care to comment?

Mr. WARD. Let me clarify our position, although it is not spelled out in this testimony. It is and it has always been that we are not advocating a return to what SCS terms "a rigid T-standard." We nevertheless believe that reference to T-value, soil loss tolerance, should be retained as a basic point of reference. The fact is that it is not under the current alternative conservation systems policy.

Our recommendation to the Department has been that, as the rule, T shall be the objective of conservation plans approved under conservation compliance, and that exceptions should be developed that would allow for erosion rates of up to 2-T in cases where it simply does not make sense, where it would cost a bundle to achieve that extra increment of erosion control.

And in areas where wind erosion is the predominant hazard, where the T calculations, or the wind erosion equation is difficult, then there should be an additional exception allowing for erosion rates of, say, up to 3-T, provided you get an erosion reduction of 80 to 90 percent in the process.

The point you raised about the difficulty of crop rotation is well taken. I think that it points out a disjunction between the existing commodity programs and the objectives of the conservation compliance provision, one that ought to be addressed in the 1990 farm bill.

So, just in summary on this point, I want to make clear that we are not advocating a rigid T-standard—rather that exceptions to T be the exception rather than the rule itself.

Mr. ROBERTS. I appreciate that, and I thank you, Mr. Ward, for responding to my rather lengthy list of questions, and it would be my hope, Mr. Chairman, that in regard to the other subject I referred to, that being risk assessment, there is a very interesting article on the front page of the Washington Post today, a fountain of all knowledge in this Nation's city, stating that we have a troublesome precedent in which a complicated scientific issue is allowed to be decided, not by officials charged with protecting the public on the basis of hard evidence, but by a frightened public acting on incomplete and often erroneous press reports.

I do not mean to prejudice any organization, or any statement, or any concern, but I would hope that this subcommittee might think about risk assessment hearings where all parties concerned could

testify to that, and that I think this is a needed debate. I think it has forced the issue. I think agriculture is now stepping up to the food safety issue much more responsibly than we have in the past, and I would urge you, sir, that we could have risk assessment hearings in which all parties concerned could testify, and I thank the chairman.

Mr. BROWN. Thank you very much, Mr. Roberts.

Mr. Ward, Mr. Roberts is really a very nice guy, and he is pleading for an improved dialog between your organization and those that you represent and the farm community, because you are natural allies in some areas, and you ought to be working together. In other areas, you may never be natural allies.

Mr. Volkmer.

Mr. VOLKMER. Yes. I apologize, I had to leave the room for awhile, and I would like to get back to your full testimony, but reading part of your testimony, it appears that you are concerned about the finding of increased methane gas. Is that correct?

Mr. WARD. That is right. We discuss that as one of three key areas where agriculture makes a significant contribution to the greenhouse effect.

Mr. VOLKMER. All right. Now, are we concerned because—I use the word "increase." It appears that is from your statement, and I just cannot, to be honest with you, find in my own mind where that increase is taking place. Can you tell me where that increase is taking place?

Mr. WARD. There is no simple direct answer to that as I understand it. I am not an expert in this area, but I believe there are——

Mr. VOLKMER. Let me ask you to do this, rather than trying to get you to answer the question, maybe Ms. Rosenzweig can elaborate on it. If she has any answers, feel free to step in.

I appreciate your going back and letting the staff come up with some of these answers in writing. We can have it either way.

But I will give you what my perception is and where I see the problem. I am not saying we do not have methane gas emissions. I know that. I know what comes from manure, and I understand from rice patties, et cetera.

The gentleman from Texas probably can be more accurate on this, but at least my perception is that our livestock production is not increasing dramatically. In fact, in some areas it is going down, and I do not believe we are producing that much more rice than we produced in the last several years.

So I am curious about why all of a sudden we are really concerned about methane gas, when that same methane gas has been out there for generations and generations?

Mr. WARD. Well, on this issue, our testimony goes to world scale, not exclusively——

Mr. VOLKMER. Now, if we are talking about world scale, then it is a little bit different.

Mr. WARD. Yes. There is a 1 percent annual increase in methane which is faster than the rate of increase for carbon dioxide, and is therefore, the subject of some concern to the scientists who are paying attention to the global-warming issue.

There are at least four things that I am aware of that have been talked about as explanations for this 1-percent trend, and those include expanded rice cultivation worldwide, increased livestock production worldwide, carbon monoxide pollution of the atmosphere, in that carbon monoxide from automobiles, and so forth, in effect competes chemically with methane, and therefore, causes a longer time to be taken for methane to be broken down in the lower atmosphere.

And the one reason that is perhaps the most alarming of all relates to the issue of positive feedbacks, in that the global-warming trend itself—the warming of the atmosphere—tends, according to the ecologists, to accelerate methane production from decay of organic matter in soils, particularly wet soils.

So those four things have been identified, in combination, as responsible for this troubling 1 percent upward trend in methane.

Mr. VOLKMER. Well, let us put it this way. If we have more wet lands—decomposition of material in those wet lands, will we have more methane?

Mr. WARD. Yes.

Mr. VOLKMER. And yet, you are saying we should have more wet lands.

Mr. WARD. I am saying we should have less global warming that, in turn, accelerates decay of organic matter in wet lands and other wet soils.

Mr. VOLKMER. Well, how are we going to prevent the decaying of that matter in these wet lands that you cannot use for anything else?

Mr. WARD. I would hope by taking actions to stem the increase in greenhouse emissions, ultimately.

Mr. VOLKMER. Well, you understand what I am getting at, don't you. Do you understand what I am saying, is that I do not see how you are going to say we should have more wet lands around. The wet lands cause some of the increase in methane, and we are not—you are not going to be feasible to be able to go out there and take all of the decomposing material out of there, a lot of which nature causes itself, and prevent that from going and being produced in that wet land and then decomposing in that wet land. We are not going to be able to do that.

Mr. WARD. Well, if you are suggesting that——

Mr. VOLKMER. I am not suggesting anything other than the fact that it is not just what see. It is just not the rice patties and it is just not the livestock out there that are causing the whole problem. And that sometimes when we think that we are doing some good in one area, which we may be doing, we may also be causing a problem in another area. That is just an observance.

Mr. WARD. I think that is right. It is obvious that methane emissions originate from natural as well as human-caused sources.

Mr. VOLKMER. That is right.

Mr. WARD. And here we have been talking about just one aspect of human-caused sources, that being agriculture. There are others, coal mining, for example.

Mr. BROWN. Let's let Ms. Rosenzweig comment on that. I hate to have the committee pick on Mr. Ward too much.

Ms. ROSENZWEIG. Another source of methane which is influenced by humans is land fill, and so that might be a better and more profitable approach in terms of limiting emissions, limiting landfills, and recycling programs. Many things could be done in the landfill area because, as you say, the protection of wet lands which have been decreasing is another important environmental goal, which may be in conflict with their methane emissions.

In terms of looking at the range of possible strategies for reducing methane emissions, wet lands may not be the best one to choose. Perhaps, as I have said, I do not know if you were here, there is potential for improved efficiency in livestock feed conversion, which would benefit livestock producers, I believe, and at the same time reduce methane emissions.

Or the same goes for rice production in rice paddies. You may be able to look for varieties of rice which produce less methane than others.

Mr. VOLKMER. On the decomposition in our landfills, there we are talking about material that indeed does decompose as far as producing the methane.

Ms. ROSENZWEIG. Yes.

Mr. VOLKMER. Right? We are not talking about cans and bottles and those type things?

Ms. ROSENZWEIG. No, no. It is from the organic matter.

Mr. VOLKMER. Organic matter, right.

Yes, Dr. Crosson.

Mr. CROSSON. I think that your question, Mr. Volkmer illustrates a key issue in this whole area of what to do about climate change because whatever we do in one area is going to comment some cost in other areas, and wet lands provide in part in social values, habitat as a flood and moderating device or mechanism and so if we set out to drain wet lands in order to reduce the methane emissions, we give up something else of value, and that cuts across the entire range of potential policies that we might consider. All of them involve some cost as well as some benefit and we need better information about those.

Mr. VOLKMER. The same way we do not want to necessarily reduce rice production, because a lot of people use rice for their diet. I think some of us would argue that we would not want to reduce our livestock production, because some of us like to eat the meat. To me it is an observation that we need to look at. Maybe we can come up with solutions somewhere along the line.

Ms. Rosenzweig, I think you have probably given the best one. If we can reduce it in that area, in the area of our solid waste disposal, it is probably less harm to everybody.

Thank you very much, Mr. Chairman.

Mr. VOLKMER. Mr. Stenholm.

Mr. STENHOLM. Thank you, Mr. Chairman.

Dr. Crosson, you summarized this panel's testimony extremely well. The question is not, can agriculture adapt, but how best can agriculture adapt.

The task over the next decade and beyond is to explore, to look, and to not be set in concrete in terms of possible solutions.

Ms. Rosenzweig, your statement concerning animal feed efficiency and the need of research within this is well taken and applaud-

ed. There are situations within our larger feedlots which will need to be examined and solutions found.

I appreciate very much you heavily emphasizing the need for research and for constantly and consistently looking for answers to some of these problems. We in production agriculture do recognize there are some problem areas that need to be studied. However, we need to work on them from the standpoint of recognizing that sometimes we do something on one hand that tends to increase problems on other fronts.

Mr. Ward, you make the statement, "expanding herds of domestic grazing animals, especially cattle". Where did you get that?

Mr. WARD. The point there is just that——

Mr. STENHOLM. You are inferring in this testimony that one of the primary causes of the methane gas problem is expanding grazing animals of domestic variety. Where did you get that information? What is your source?

Mr. WARD. Right. A story in the Wall Street Journal. It says a new——

Mr. STENHOLM. The Wall Street Journal? You read it in the Wall Street Journal and you come before this committee and state that one of the primary causes of methane gas is due to expanding herds of domestic grazing animals, especially cattle. Is that true?

Mr. WARD. I believe it is. The agricultural sources that contribute to methane emissions are in fact rice production and livestock production—and those two, according to the literature that we have looked at which admittedly is not much—there is not much in this area——

Mr. STENHOLM. That is my problem with your testimony. Twice today, Mr. Ward, you have stated, "I don't presume to have all the answers but, I am not an expert in this area, but."

Now that is my problem with you and your organization. You honestly admit you do not have all the answers, but you then in turn make statements on the record that are picked up by the press that do suggest that you do have the answers.

When you say "especially cattle", you have got some different figures than I do. In 1970, we had 12 million dairy animals, today we have 10,243,000. So we have declined by 1,757,000 dairy cattle since 1970. In 1975, we had 132 million beef cattle. Today we have 99 million beef cattle. That is a decline of 33 million head.

So I say where did you get your information?

And, Ms. Rosenzweig, you can answer the question for him.

Ms. ROSENZWEIG. I think one of the problems here is that for the sources of emissions and those figures, the scientists who estimate those numbers look globally at what is going on in India, Bangladesh, and all developing countries. Because in some of those other areas there has been an increase—I am only surmising because I do not know where NRDC got their data—but I do know that people at the Institute where I work, Goddard Institute of Space Studies, are involved in looking at the census of animal populations over time, globally.

So while it may be true that in the United States—I think—the figures you were just reading were from the United States?

Mr. STENHOLM. Yes.

Ms. ROSENZWEIG. Yes, that is definitely true that it may be decreasing here, but we have to look globally. So perhaps that comment is aimed more at a global look, not necessarily in the United States.

Mr. STENHOLM. My point is when we start saying, "I do not have all the answers, but," this is not helpful. We are concerned on this subcommittee about our domestic agricultural policy. There is very little that we can do on this committee that will mandate changes for the rest of the world in terms of their domestic cattle feeding practices.

I respect your opinions, but I get very concerned when you come up here and state "I don't have the answers, but, I am going to go ahead and give you some anyway," and then the next thing you know you are given credibility without having the scientific basis behind you.

Mr. WARD. Let me just say on the grazing issue, nothing in this testimony is intended in any way to be an assault on domestic livestock industry. I would accept that this characterization is probably not as precise as it might be. We are in fact just trying to make a general point that on a world scale the evidence seems to suggest that livestock grazing is comparable to rice production as an agricultural contributor to methane emissions, that is all.

And in terms of policies recommended, that is part of a comprehensive systems research effort that this be one area that USDA should examine, and in that context, develop some possible responses for this country and the rest of the world. That is where it stops and that is what I suggested to Mr. Roberts as well.

I mean we are not talking here about a Government mandate that in any way would be intended to injure this country's livestock producers. I want to make that clear.

Mr. STENHOLM. I appreciate that clarification because I think that is extremely important.

By the way, for the record, world cattle numbers have declined too.

Ms. ROSENZWEIG. Have they?

Mr. STENHOLM. World cattle numbers have declined at least in the last 3 years.

Ms. ROSENZWEIG. Well, it shows the uncertainty of where that increase is coming from. It is unknown.

Mr. STENHOLM. Mr. Chairman, in reading the statements of each of you and also the previous panel, there is not a doubt in my mind we need to do more in the area of research to find some of the answers. I am very concerned that we make knee jerk reactions and allow things to happen because of sensationalism in the press.

There are far more questions than there are answers out there, at least in this member's mind.

I would much rather us try to put our shoulders to the wheel collectively and fund some needed research.

Thank you, Mr. Chairman.

Mr. BROWN. Thank you very much, Mr. Stenholm.

The discussion here this afternoon strayed a little bit from what we intended, but it is very illustrative of the interrelationship between science and policy that is a problem that faces us all along here.

For an example of this, we have the problem of BSD bovine somatatropen, which is intended to increase the production of milk from dairy animals with a decrease input of feed. It obviously can only do that with increased efficiency of feed utilization.

This is a positive in terms of the emission of methane from animals. It should be a positive in terms of the increased profitability of milk production, yet it will also have some negatives from a policy standpoint amongst which may be eliminating a third of the dairy farmers in the United States. We have to be conversant with all of the potential impacts, both good and bad, when we look at a particular approach to a problem that faces us here.

I think that we all have somewhat better understanding of this complexity as a result of the exchange that we have had here and the need to be very, very careful first in combining research with policy, and second, in developing appropriate policy after we have sufficient facts which will enable us to move ahead, which is the thrust of this hearing.

We are trying to identify the research deficiencies and the policy areas in which we can move, and that requires sufficient agreement amongst all of the actors in order to get some sort of a political consensus.

Despite all of the discussion, I think we have moved forward in that direction, and I am not going to belabor the point particularly. We have gone beyond the time that we had anticipated here.

You have no further questions?

Mr. VOLKMER. No, Mr. Chairman.

Mr. BROWN. I think I will dispense with those that I had and we will ask you, if you would, to respond in writing to any remaining questions.

I am very grateful for the testimony that all of you have given here this morning. Thank you very much.

The subcommittees will be adjourned.

[Whereupon at 12:40 p.m., the hearing adjourned, subject to the call of the Chair.]

[Material submitted for inclusion in the record follows:]

Statement of Orville G. Bentley
Assistant Secretary, Science and Education
U.S. Department of Agriculture
Before the Subcommittee on Department Operations,
Research and Foreign Agriculture, and the Subcommittee on
Forests, Family Farms, and Energy, of the
Committee on Agriculture
U.S. House of Representatives
April 19, 1989

Mr. Chairman, I appreciate the opportunity to appear before you and the Members of the Subcommittees to discuss activities of the U.S. Department of Agriculture (USDA) as they relate to the potential effects of global warming on U.S. agriculture.

I represent the Department on the Federal Coordinating Council for Science, Engineering and Technology, Committee on Earth Sciences. By virtue of this responsibility, I serve as the principal coordinator for USDA's activities relating to research on global climate change. I have with me Dr. Norton D. Strommen, Chief Meteorologist, World Agricultural Outlook Board; Dr. Mike Fosberg, Research Meteorolgist, U.S. Forest Service; Dr. Doral Kemper, National Program Leader on Atmosphere, Agricultural Research Service, and; Dr. Boyd Post, Forest Biologist, Cooperative State Research Service.

Concerns about the effect of climate change on agriculture are not new to USDA. The potential exists for climate change to impose significant adverse effects on agricultural production. To address this issue, we have taken steps to predict and assess impacts of the greenhouse effect and other potential climate threats. We need to know what could happen and what can be done to ensure dependable supplies of food and fiber.

There are climate experts who claim 1988 was evidence that global warming has already begun. A conclusive link has not been proven, but the threat of global warming from heat trapped by so-called greenhouse gases--carbon dioxide, halons, and other trace gases--is too much of a risk to ignore.

We don't have to look very far for an example of what industrial and automobile emissions of gases already have done in the country. USDA studies, some dating from the 1950s, have shown damage to crops and trees from atmospheric pollutants, including low-level ozone.

We need the research called for in this strategy as insurance against changes we may never see. What we learn will help farmers and ranchers cope with drought and high temperatures in the future, even if greenhouse warming never materializes. It is critical that the Department be ready to maintain food production under varying conditions.

Computer simulation models will play an essential role in USDA's efforts. They allow us to simulate the effect of future climate scenarios on the agricultural system. To develop the basic scientific information needed by the models, department specialists will rely on data from laboratory studies, outdoor crop growth chambers and open field experiments where carbon dioxide is released and increased levels of ozone and ultraviolet radiation are provided to simulate certain conditions. Other experiments will test the validity of the simulation models and economic analyses will assess the effects of climate change on farm costs and the marketplace.

We need to find out not only how these changes might harm agriculture, but also how agriculture might be contributing to the changes.

Several strategic planning activities regarding global climate change have spanned the past 12 to 15 years. The most recent effort was completed and published in three volumes by the National Defense University, Fort McNair, Washington, D.C. These publications reflected the best estimates of our future climate based on state-of-the-art knowledge at that time. But since then new information has become available, including the potential threat of elevated levels of ultraviolet radiation stemming from stratospheric ozone depletion. This threat, added to those stemming from increased atmospheric carbon dioxide concentration, give USDA valid reasons to be concerned about the potential effects of climate change in this Nation, as well as in the world.

USDA is closely monitoring reports of carefully documented increases in levels of carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and other trace greenhouse gases in the environment. All of these gases can, in theory, contribute to the warming of our atmosphere. In addition, some of them deplete ozone from the stratosphere, reducing the effectiveness of the earth's ultraviolet radiation shield. Carbon dioxide, in addition, can have a direct positive effect on the growth of crops.

The Department's research program for global climate change has two basic parts: 1) dealing with the impact that changing climate could have on the stability and productivity of our natural resource and agricultural ecosystems; and 2) developing strategies to reduce climate change by managing natural resources and agricultural ecosystems to sequester carbon dioxide and reduce the emissions of other greenhouse gases. As the lead food agency, USDA's primary responsibility is with the first of these, but there are significant opportunities for USDA to make a difference in the second -- particularly in the management of our forests and agricultural crop production, as I will point out in more detail later.

Mr. Chairman, the nature and pace of climate change is uncertain and that there appears to be a lag between emissions of greenhouse gases and their impact on climate. This lag time presents special difficulties in forest management. The age of some forest stands is over 100 years. The Forest Service is faced with assessing the potential impact of future climate changes, as well as assessing the impact of changes in local air pollution. The forests that exist now were produced under different environmental conditions than exist today. Even without future climate changes, tomorrow's forests could be quite different.

Even though the nature and pace of climate change is uncertain, the lag time involved in its potential impact on agricultural systems makes it essential that we do not wait until the change occurs to develop response strategies. A healthy agricultural system is essential to the Nation's security. Anything as critical as our food, fiber, and water supply requires that we have the capability to deal with a range of future possibilities, including the worst case.

Dealing with possible future scenarios that have never existed requires a new approach to our research. No longer can we extrapolate past experience into the future. To deal with this future we must understand the basic physical, chemical and biological processes involved in complex ecosystems with sufficient accuracy to predict responses to any possible climate scenario. Because we cannot conduct experiments on the actual system of the future, we must construct simulation models for study. This is a formidable task. The effects of global climate change cannot be assessed by focusing narrowly on only one or two specific sources of effects or ecosystem receptors.

Because climate change will induce a multiple set of stress factors on the agricultural system, predictive models to deal with it must be comprehensive. A USDA strategic plan for climate change research must recognize that for different applications separate model types will be required. These models must be developed during the early stages of data collection and will serve as the framework for monitoring and defining future research needs.

Our agriculture is highly diverse across the Nation. A model that predicts possible climate change at a global or national scale is of little value in making intelligent decisions related to forest and agricultural productivity. We need climate prediction at the local and regional scale, and particularly we need to know the distribution of rainfall and temperature throughout the year, and the variability of these patterns from year to year. We realize that today's computer-driven models do not now permit predictions of future climate and environment to be made at this scale, but we are working closely with those who are developing global circulation models to help them understand the agricultural needs based on the complex interactions between climate and agriculture and forestry production. These interactions must include the capability of managers to adapt either through changing the genetic structure of crops plants or through other management options that are available from application of existing agrometeorological knowledge.

Agencies of the USDA included in an effort to develop a strategic plan for climate change research are: the Agricultural Research Service (ARS), Cooperative State Research Service (CSRS), Forest Service (FS), Soil Conservation Service (SCS), and World Agricultural Outlook Board (WAOB).

In addition, the Economic Research Service (ERS) and Extension Service (ES) will conduct policy analyses and extend new management practices to farm operators. These agencies form a team with the capability of addressing the major components of natural resource and agricultural ecosystems and their responses to global climate change in the U.S.

The WAOB, the hub of a network of cooperating agencies, is responsible for coordinating the estimates of the world's agricultural production in real time on the basis of environmental data from a number of sources. This agency and its cooperators have developed databases and analytical techniques that represent a substantial resource for predicting world crop production under a range of climate scenarios. Global climate warming could cause significant reduction of food production of some countries. Under some estimates of possible sea level rise, for example, food production from low-lying countries such as Bangladesh could be nearly eliminated. ERS will help assess the impact such production displacements could have on the world market and changes in demands that could be imposed on the U.S. agricultural production system.

The SCS has developed and maintains the Nation's database of soils. This soils database will be singularly important in assessing the potential impact of regional changes in climate on agricultural productivity. One possible scenario predicted by one global circulation model is for the Corn Belt to move northward. If the soils to the North were equally deep and fertile, as those of the Corn Belt, such a change might only represent a geographic displacement of production. But the soils to the North have been glaciated, and generally have much lower water holding capacity and fertility.

The productivity of any site depends on both climate and soil resources. SCS will provide the needed soils data for predicting the impact of climate change on agricultural productivity and for developing strategies for managing soil and water resources to undergird a productive and sustainable agriculture with a changed climate.

Climate change may also have significant impact on the Nation's forests and related ecosystems. These changes would require FS and other land managers to respond with effective management practices to protect and maintain forest health and productivity. There are two basic issues or questions that must be addressed. What effect might climate change have on American forests, and what should forest managers do to be prepared to sustain the future health and productivity of American forests?

A number of future scenarios have been constructed from climate change predictions and some include major changes in the distribution of important timber species. Since public lands in the West are also the major source of water for agriculture, domestic and industrial use, future water supply and quality are also issues that must be addressed. Protection of our renewable resources from fire, insects and diseases is also important. Future protection required to maintain the health and productivity of our forests needs to be determined.

Most strategies to reduce the impact of the greenhouse effect call for energy conservation or conversion to alternate energy sources to reduce the carbon dioxide flux to the atmosphere. An aggressive reforestation or afforestation program could theoretically change the direction of carbon flux. It would take a reforestation program in which 100 million hectares, or approximately 2.5 percent of the earth's forests, of vigorous, rapidly growing, wood vegetation planted annually to offset man's contribution to atmospheric carbon dioxide by fossil fuel combustion.

The recently passed and signed Forest Ecosystem and Atmospheric Pollution Act of 1988 (PL 100-521) identified the need for research on effects of atmospheric pollutants on forest ecosystems. The act recognized that multiple stresses may be responsible for forest decline. The Forest Service Strategic Research Plan calls for a four-element program addressing: Effect of the Atmosphere on Ecosystems, Effects of Ecosystem Changes on the Atmosphere, Assessment of Long-Term Changes, and Ecosystem Modeling, in order to apply research finding to management of our renewable natural resources.

FS research will contribute significantly toward our capability to predict species distribution for future climate scenarios. The long-range renewable resource management program will focus on the development of 1) physiologically-based models to predict the effects of possible global climate changes, 2) models showing the biophysical effects of such changes, 3) methods to link these models, and 4) economic impact and risk assessment models.

CSRS effectively links together the resources of the Nation's agricultural experiment stations and forestry schools. Located in all 50 States, the District of Columbia, Puerto Rico, Guam, the Virgin Islands, the Northern Marianas, Micronesia, and American Samoa, these institutions provide the expertise of university scientists in developing the fundamental theories and technology needed to predict and validate global climate change and its consequences to local and regional agriculture and forestry.

University scientists have been organized in a regional research program for several years with a number of projects which specifically work on agricultural climatology, crop, forage and forest responses to environmental influences, including carbon dioxide, ozone and other gases, temperature, light, humidity and all other environmental variables.

The universities and experiment stations have programs in genetics and biotechnology in place to develop crops, animals and forest trees adapted to conditions which will be present in the future.

With an appropriation of $3.7 million for Fiscal Yeat 1989, CSRS initiated a program of competitive grants to explore the effects of increased UV-B radiation on crop growth and productivity. An increase proposed for 1990 would broaden the scope of the program to explore plant responses to other stimuli which would change under global warming scenarios. This expanded program is critical to developing a more complete understanding of global change impacts on food and fiber production.

With substantial funding from the Department of Energy (DOE), ARS is developing considerable expertise in the construction of computer facilitated, process level crop simulation models. In cooperation with university scientists, ARS has pioneered the development of computerized agricultural decision support systems using artificial intelligence techniques to help farmers make decisions for managing irrigation, fertilization and other crop management factors.

Recently funds have been appropriated for incorporation of ultraviolet radiation (UV-B) as a specific variable in these crop simulation models. With expanded support, ARS scientists will develop a library of modules for physiologically-based crop growth simulators that will include atmospheric carbon dioxide and UV-B radiation intensity as explicit variables. These modules will serve as a foundation for computerized decision support systems for managers of agricultural systems that include a range of crop and animal enterprises. These farm-level decision support systems will, in turn, provide the foundation for models constructed to assess the risk and economic impact of possible global climate change for the Nation and for the world.

ARS scientists will work closely with ERS and others to develop linkages between these models and economic models. Considerable effort will be required to develop the basic knowledge of the processes involved in these models as well as the data required to run them.

The current emphasis and concerns about global climate change are placing added pressure on ongoing research and development programs, as previously indicated. USDA, through its network of Federal and university research facilities distributed throughout the U.S., has the capacity to redirect research activities and initiate new projects related to climate change. Research on southern ecosystems would be transferrable north, should warming trends cause growing zones to migrate northward. Research locations in semi-arid areas can provide data for adaptation to areas that might become drier with climate change. USDA can use much of its ongoing research to support the development of new knowledge and technology for the eventualities of climate change.

ERS has the capacity to develop policy analyses to provide the Secretary of Agriculture with options for encouraging regional shifts in cropping systems, conservation reserves and acreage set-asides to maintain strategic reserves for food. Much of its success, however, will depend on the lead time that can be gained through accurate predictive capability through simulation modeling.

This type of research requires considerable computer capability and large-scale databases. To acquire such massive data sets in the short period indicated will require major shifts in currently funded research projects in ARS, FS, and at the agricultural experiment stations.

Mr. Chairman, I would be remiss if I did not point out that USDA is a member of the Intergovernmental Panel on Climate Change. Our efforts are, as this statement reflects, coordinated to achieve maximium effectiveness. Thank you for the opportunity to present the current state of USDA research activities related to the potential effects of global climate change.

TESTIMONY OF

DR. ALAN R. THOMAS
ACTING ASSISTANT ADMINISTRATOR
OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U. S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON DEPARTMENT OPERATIONS, RESEARCH, AND FOREIGN AGRICULTURE
AND THE SUBCOMMITTEE ON FORESTS, FAMILY FARMS, AND ENERGY
COMMITTEE ON AGRICULTURE

U.S. HOUSE OF REPRESENTATIVES

APRIL 19, 1989

Mr. Chairman and Members of the Subcommittees:

My name is Alan Thomas. I am the Acting Assistant Administrator of NOAA's Office of Oceanic and Atmospheric Research. I appreciate the opportunity to present to you NOAA's efforts in global change research. As you requested, I will focus on our interactions with national and international global change efforts, and on our interactions with the Department of Agriculture.

NOAA's Climate and Global Change Program

NOAA has recently embarked on its Climate and Global Change Program. This is a NOAA-wide program developed to address the global climate system with the broad goal of establishing a new national information service based on the achievement of reliable assessments and quantitative predictions of changing global climate. The program builds on NOAA's role as an operational,

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prediction, and information agency. In line with NOAA's responsibilities for extended range weather forecasting, the near-term objective of the program will be to provide reliable predictions of global climate change and associated regional implications on time scales ranging from seasons to centuries. Specifically, the NOAA Climate and Global Change Program will address four scientific issues:

- Long-Term Observations: A well-focused expansion of NOAA's environmental observing system is essential for developing a predictive capability for climate. Building on current weather and satellite observing systems, the program includes: an expanded ocean observing network, global sea level measurements, monitoring the stratosphere to detect change, and satellite instrumentation to support the global change effort.

- Climate Process Studies: To attain the desired predictive capability, NOAA will undertake a research program to understand and describe critical processes and conditions which characterize changes in the global climate system. The research areas are designed either to resolve a difficult part of the climate problem or to develop predictive models for specific climate change mechanisms. This includes continuation of the NOAA Radiatively Important Trace Species (RITS) program

and the Tropical Ocean-Global Atmosphere (TOGA) program, and studies of the hydrological cycle.

- Climate Diagnostics and Prediction: This will ultimately be the central component of NOAA's Climate and Global Change Program. This program will synthesize the results of the other programs into meaningful climate predictions, assessments, and related information. The elements are: climate diagnostics, modeling and prediction, and regional assessments.

- Climate Data Services: NOAA will support activities leading to climate data bases, data sets, and data fields to meet user requirements and be easily accessible to the global change community.

The U.S. Global Change Research Program

The U.S. Global Change Research Program is an interagency effort to coordinate research in global change. This program is being developed through the Committee on Earth Sciences, a component of the Federal Coordinating Council for Science, Engineering, and Technology. Seven Federal agencies, including NOAA and the Department of Agriculture, are participating in the program.

The goal of the U. S. Global Change Program is to establish the scientific basis for national and international policy-making

4

related to natural and human-induced changes in the Earth system. To attain this goal, the Program looks to understand the forces which initiate global change, how the Earth system responds to changes in these forcing functions, how the Earth's environment has changed in the past, and to determine how well global change can be predicted.

The U.S. Program has three scientific objectives: monitoring, understanding, and predicting global change. Inquiry into these areas will provide an assessment of the state of knowledge of both natural and human-induced changes. Monitoring of the Earth system allows for observation of any changes in the system. The data collected through monitoring can also be used to test models and predictions.

Many physical, chemical and biological processes need to be understood because they greatly affect the global climate system. For example, the sources, sinks, and transport of chemical constituents and energy are not yet well understood; however, they have a tremendous impact on the climate system. Methane is an important greenhouse gas; but its sources and sinks are not well known. As climate changes, many systems will adapt through various feedback mechanisms which will either enhance or lessen the change, or even introduce a different change. These feedback mechanisms have yet to be understood and some may not even be known as yet.

Finally, models must be developed to describe and predict the climate system. These models will use both observational data and any new understanding of processes gained from the program. This will enable the models to produce reliable predictions on both global and regional scales.

NOAA is an active participant in the U.S. Global Change Research Program. NOAA's role is based on its history and experience with observations, analytical studies, weather and climate prediction, and information management. Accordingly, NOAA will provide improvements in climate change predictions, and its regional implications, on time scales from seasons to centuries. NOAA's mission-directed activities include: operational in situ and satellite observing programs; research on physical and biogeochemical processes in the climate system; development, testing, and application of predictive models and diagnostic techniques for detecting natural and human-induced changes; and acquisition, maintenance, and distribution of long-term data bases and related climate information. These elements are all part of NOAA's Climate and Global Change Program described previously.

International Efforts

Several international efforts are underway to investigate global climate change. The World Meteorological Organization and the United Nations Environment Program are sponsoring the Intergovernmental Panel on Climate Change (IPCC). The IPCC will:

review the state of the science of climate change; review and conduct studies of social and economic impacts of climate change; and develop and evaluate possible policy responses. The U.S. effort in the scientific assessment is being coordinated through the Committee on Earth Sciences by Dan Albritton of NOAA and Robert Watson of NASA. The scope of the Assessment will cover all aspects of climate change with a special emphasis on identifying gaps in knowledge and a quantification of uncertainties. The Assessment is scheduled to be given to the IPCC in September, 1990.

The U.S. Global Change Research Program is being developed, and will collaborate with international global change programs. For example, the International Geosphere-Biosphere Programme, under the direction of the International Council of Scientific Unions, is a major international effort to understand the processes which regulate the climate system, changes occurring within the system, and how the system is being influenced by human activity. The U.S ccntributions will include: water-energy-vegetation interactions; fluxes of material between terrestrial systems and the oceans and atmosphere; biogeochemical dynamics of ocean interactions; earth system history and modeling; and human interactions.

NOAA Climate Services

NOAA will continue to provide climate services as its Climate and Global Change Program works toward its objective and

goal. NOAA's Climate Analysis Center (CAC) monitors, diagnoses, and predicts short-term climate fluctuations. The CAC produces monthly and seasonal outlooks and weekly and monthly analyses. The Joint Agricultural Weather Facility is a cooperative effort between CAC and the Department of Agriculture. This group publishes the Weekly Weather and Crop Bulletin. An agreement is pending between CAC and the U.S. Forest Service to formalize working relationships for enhanced fire weather services.

NOAA's National Climate Data Center (NCDC) collects, archives, processes, and disseminates climatological data; develops analytical and descriptive products; and provides historical analyses and interpretations of climatological data. NOAA, through the National Climate Program Office, supports the Regional Climate Centers (RCC's). These centers address the regional and local aspects of climate and interface with both CAC and NCDC.

NOAA and the Department of Agriculture, along with several other Federal agencies, cooperatively produced U.S. Drought 1988: A Climate Assessment during the severe drought last summer to accompany the report to the President by the Interagency Drought Policy Committee.

NOAA research laboratories support climate services and are addressing climate issues, some of which impact agriculture. NOAA's Geophysical Fluid Dynamics Laboratory develops weather and global climate models to improve our ability to predict climate

variables such as soil moisture and precipitation. We expect the new, seventh generation supercomputers to provide the capability for incorporating processes, such as land surface exchanges, to improve climate models. NOAA's Air Resources and Aeronomy Laboratories are investigating why high levels of ozone exist in rural areas. This is important because of the foliar plant damage ozone can cause. In addition, NOAA's Climate Analysis Center published a weekly drought advisory report during the summer of 1988, incorporating information from several Federal agencies, including the Forest Service. The reports were distributed to Federal Administrators, Congressional staff, private industry, and the media.

In conclusion, NOAA is very much involved in the science issues surrounding global climate change and in providing the available climate information and data for use in U.S. decisionmaking. NOAA's Climate and Global Change Program will coordinate with the national and international efforts to understand the climate system and to ultimately predict what will happen to it.

This concludes my prepared remarks. I would be pleased to answer any questions you may have.

NASA
National Aeronautics and Space Administration

Hold for Release Until
Presented by Witness

April 19, 1989

Subcommittee on Department Operations, Research, and Foreign Agriculture

Subcommittee on Forests, Family Farms, and Energy

Committee on Agriculture

House of Representatives

Statement by:

Dr. Shelby G. Tilford
Director,
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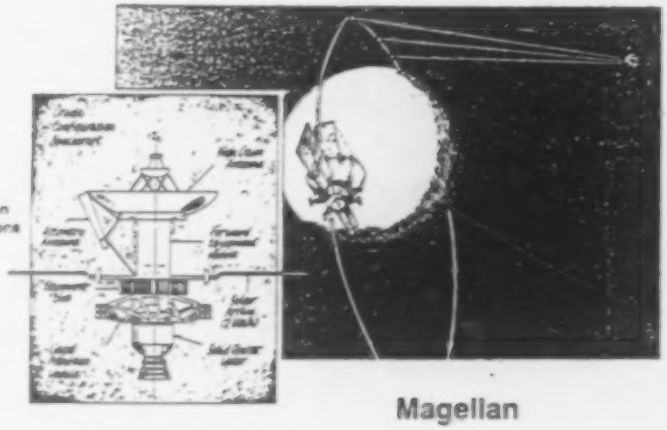

Magellan

101st Congress

STATEMENT OF

DR. SHELBY G. TILFORD

BEFORE THE

SUBCOMMITTEE ON DEPARTMENT OPERATIONS, RESEARCH, AND FOREIGN AGRICULTURE

SUBCOMMITTEE ON FORESTS, FAMILY FARMS, AND ENERGY

COMMITTEE ON AGRICULTURE

HOUSE OF REPRESENTATIVES

Mr. Chairman and Members of the Committee:

I am pleased to be here today to discuss NASA's commitment to providing an improved scientific understanding of both natural and human induced changes in the Earth's environment, with an emphasis on climate change. In this testimony, I would like to describe for you briefly the current state of knowledge of climate change; an outline of the scientific assessment of global climate change that will be conducted under the auspices of the International Panel for Climate Change (IPCC) of the World Meteorological Organization (WMO) and United Nations Environment Program (UNEP); the type of scientific information needed to predict future global change; the scope and content of NASA's Earth System Sciences program; and how it is coordinated with the scientific community and other federal, specifically the Committee on Earth Sciences (CES), and international agencies and programs, e.g. the International Geosphere Biosphere Program of the International Council of Scientific Unions and the WMO World Climate Research Program.

Our Changing Planet

It is evident that the Earth is a planet characterized by change. We have now entered an era in which the human race may have achieved the ability to alter its environment on a global scale. The ozone and global greenhouse warming issues, which are presently at the center of attention of many scientists and policymakers, are just two of the interrelated environmental issues we face today. Others include such issues as deforestation, desertification, acid rain, and river and oceanic pollution.

To gain a scientific understanding of how human activities will affect the Earth's environment requires a new approach to Earth sciences. The Earth's environment is a dynamic system that changes on all time and space scales. These changes can have tremendous impact on human welfare. Some of these changes may stem from natural processes that began millions of years ago. Some may be influenced by human activities. However, at present, we do not know the relative contributions of natural processes and human influences on these changes. It is vital that a scientific understanding of the Earth system be obtained on a global scale by describing how the environment's component parts and their interactions have evolved, how they function, and how they may be expected to evolve in the future on all time and space scales.

The immediate challenge is to develop the capability to predict the environmental changes that may occur in the next decade to century, by both natural and human influenced processes. This will require a nationally and internationally coordinated program of interdisciplinary research to investigate long-term, 10-100 years, coupled physical, chemical, and biological changes in the Earth's environment recognizing that land, atmospheric, oceanic, and biospheric processes are strongly coupled on a variety of temporal and spatial scales. Wise policymaking requires this improved scientific understanding of our planetary life support system.

Brief Outline of the Current Scientific Understanding of the Greenhouse Effect

1) There is now compelling observational evidence that the chemical composition of the atmosphere is changing at a rapid rate on a global scale. The atmospheric concentrations of CO_2, CH_4, N_2O, and CFCs 11 and 12 are currently increasing at rates ranging from 0.2 to 5.0% per year. The atmospheric abundances of these gases are higher today than during the period of recorded observations (160,000 years ago from the ice core records). These changes in atmospheric composition reflect in part the metabolism of the biosphere and in part a broad range of human activities, including agricultural and combustion practices.

2) These gases alter the Earth's radiative balance through the greenhouse effect.

3) There is evidence that the global mean temperature has increased by about 0.5 degrees centigrade since the late 1800's. However, the temperature increase has been neither monotonic with time, nor uniform over the globe. The increase in global mean temperature has occurred in a stepwise fashion with significant increases in the 1920's and 1930's and recently again in the 1970's and 1980's. The temperature over the continental United States has not increased to the same extent, if at all, as that reported globally, and the temperatures of the southern oceans have increased much more than those of the northern oceans.

4) While the overall increase in global mean temperature is consistent with that expected from the increase in greenhouse gases, the regional and temporal details of the observed

versus predicted changes need to be more carefully examined. Differentiating between natural and human induced changes in regional temperatures requires a significant improvement in our data base and in our understanding of the global earth system.

5) While all General Circulation Models (GCMs) predict an increase in the global mean temperature of between approximately two and five degrees centigrade for an "effective doubling" of atmospheric carbon dioxide, there are significant differences in the magnitudes of the predicted regional and seasonal temperature changes. Similarly, it should be noted that while all GCMs predict an overall increase in global precipitation, predictions of changes in the amount of regional precipitation differ even in sign for key areas in the continental United States. Therefore, GCMs are currently not capable of reliable predictions of climate change at the regional scale.

6) The timing of the predicted climate change is also somewhat uncertain because of an inadequate understanding of how energy and chemicals are exchanged between the atmosphere and the oceans. The large heat capacity of the oceans delays the realization of the predicted equilibrium warming.

Understanding of what initiates not just climate change but all forms of global change requires an understanding of the forcing functions of the system. Prediction of the magnitude and timing of global change requires an understanding of the planetary response processes. Knowledge of planetary response leads to understanding the consequences of global change. Scientific knowledge and the ability to accurately predict the magnitude, timing, and consequences of global change is required in order to formulate policy that can responsibly deal with global change.

Man's Role in Changing the Environment

The possibility of a global warming due to the greenhouse effect, and the clear signs of polar ozone depletion, are only two among a number of possible global changes which could possibly occur over the next 10 to 100 years. Other manifestations of global change include deforestation in the tropics and at mid-latitudes and desertification in marginal agricultural areas of some continents. Some change is due to natural causes, while some may be due to man's activities.

Examples of natural long-term changes include solar variation, and the orbital variations of the earth about the sun, called Milankovich cycles, which are believed responsible for the cycle of ice ages on the earth. Other natural changes occur on shorter time scales, such as volcanic activity and the El Nino Southern Oscillation, which is a naturally recurring event of varying magnitude and periodicity.

Examples of human activities that may potentially lead to global change include fossil fuel burning, industrial effluents, refrigerating agents, aerosol and solvent usage, and land practices involving agriculture, food production and deforestation.

The global environment is changing. There are documented changes in global atmospheric composition that could lead to changes in global climate. There is massive ozone depletion over the Antarctic, with implications for ozone depletion at mid-latitudes. Tropical forests are being depleted, with possible consequences for global climate. Marginal lands are being converted to desert by non-conservative agricultural practices, with implications for regional climate.

The effect of man on the environment must be quantified and understood in the background of natural change. Unraveling change due to natural and man-made causes is a difficult

task that requires a better understanding of the earth as a global system, together with the processes that create global environmental balance, and the processes that can lead to a change in that balance. Our understanding of the earth system is not now sufficient to quantify the contributions of natural processes and human influences to global change.

A better understanding of the earth system, and the development of the ability to predict long-term global change in the earth system, are at the foundation of the U.S. Global Change Program.

The Need for Reliable Prediction of Global Change

Accurate prediction of global change is important because of the potential severe impacts on society, industry, and the domestic and foreign policies of the United States Government. We are constantly reminded of the economic loss that global change can cause. The 1982-83 El Nino event caused billions of dollars of loss, and the 1988 summer drought in the U.S., while most likely the result of natural fluctuation in the climate system superimposed on a possible long term warming trend, provides examples of the possible consequences of global warming.

The consequences of global change need to be predicted, whether occurring by natural or man-made cause, in order to develop wise policy to deal with such change. The types of global change which can result in the redistribution of global resources and economic potential include the spatial and temporal distribution of temperature, precipitation, severe storms, drought, change in agricultural productivity, sea-level, water resources and human health.

Energy, agricultural, natural resource, coastal zone, and water resource policies will all be influenced by a significant change in climate. If we want to understand how changes in the physical climate system (temperature, precipitation, frequency and magnitude of severe weather) will impact agricultural and energy policies, we need to improve our scientific knowledge of ecosystem response to these changes.

What Scientific Knowledge is Required to Accurately Predict Global Change?

The Committee on Earth Sciences (CES) of the Federal Coordinating Council on Science, Engineering and Technology (FCCSET) has described the scientific knowledge required to accurately predict global change in its document "Our Changing Planet: A U.S. Strategy for Global Change Research" which was submitted to the Congress with the President's FY1990 budget:

'A better predictive understanding of global change requires improved answers to the following four major questions that form the core of the U.S. Global Change Research Program research agenda:

1. What Forces Initiate Global Change?

These forces include changes in solar irradiance, in the abundance of atmospheric trace gases and aerosols, in land use, in biota, and in the earth's orbit.

2. How Does the Earth System Respond to Changes in Forcing Functions?

These responses or "feedbacks" include interactions among the climate, the ocean, the land, the biota, and the atmosphere.

3. How Has the Earth's Environment Changed the Planet?

Differentiating between natural and human-induced global change requires clear documentation of the history of the earth system variations over long time scales, especially prior to the influence of human activity. This documentation is provided by fossils, tree rings, pollen, soil composition, and sediments from the ocean, land, and ice.

4. How Well Can Global Change be Predicted?

These evaluations include the ability of models to simulate past and present global changes and the biological responses to these changes.

Rational response strategies and sound policy can only be built upon reliable information, predictions, and assessments of the complex phenomena of the global earth system. It is in this context that the U.S. Global Change Research Program ... has been developed.'

Planning and Agency Roles for Global Change Research

The U.S. Global Change Research Program is being developed by the Administration through the Committee on Earth Sciences (CES), which is an interagency committee of FCCSET, established by the Office of Science and Technology Policy (OSTP). To date, the CES has been extraordinarily successful in coordinating Federal agency programs towards a common U.S. goal in Global Change.

The detailed planning of the U.S. program is being done by the CES in conjunction with the scientific community through the National Academy of Sciences (NAS) Committee on Global Change. NASA participated fully in the preparation of the document "Our Changing Planet: A U.S. Strategy for Global Change Research", and is now actively participating with the CES in the preparation of a more detailed and comprehensive U.S. Global Change Research Program implementation plan.

The goal of the U.S. Global Change Research Program as defined by the CES is:

"To establish the scientific basis for national and international policymaking related to natural and human-induced changes in the global earth system."

To accomplish this goal, the CES has derived three objectives for the U.S. Global Change program:

1. Establish an integrated, comprehensive monitoring program for earth system measurements on a global scale.

2. Conduct a program of focused studies to improve our understanding of the physical, chemical, and biological processes that influence earth system changes and trends on global and regional scales.

3. Develop integrated conceptual and predictive earth system models.

These goals and objectives are fully consistent with those proposed by the NAS Committee on Global Change and with those proposed by the International Council of Scientific Unions (ICSU) for the International Geosphere Biosphere Program (IGBP). The NAS and ICSU programs are still being formulated and will build upon the many ongoing

national and international research programs in Earth sciences and will not duplicate or replace them.

The roots of the U.S. Global Change Research Program can in many ways be traced to the recommendations of the Earth System Sciences Committee (ESSC) established in 1983 by the NASA Advisory Council. The ESSC provided NASA, NOAA, and the NSF with a clear definition of their specific roles in Earth System Science. The ESSC recommended a comprehensive Earth Science Research Program involving space-based, suborbital, land-based, and sea-based measurements; laboratory, theoretical, and instrument and model development studies, with national and international cooperation and participation.

The NASA portion of this plan is based on continued strong support for the Research and Analysis programs described below, expansion of the concept of the interdisciplinary research program, completion of approved satellite programs including the Upper Atmospheric Research Satellite (UARS), the Ocean Topography Experiment (TOPEX/POISEDON), the NASA Scatterometer (NSCAT) planned to fly on the Japanese ADEOS satellite, and the future initiation of the planned Earth Observing System (Eos) which will make use of the polar platforms being developed as part of the International Space Station effort.

Any future interdisciplinary, integrated Earth Science program will require an interactive Global Resource Information System. NASA has initiated a number of pilot programs to establish the requirements for such a system. Specifically, the two critical issues being addressed are:

(1) how best to create a data management system capable of dealing with interdisciplinary and multidisciplinary questions of global scope, and

(2) how best to provide, in advance, for handling the unprecedented flow of digital information that will be generated by the polar orbiting space platforms planned for Eos.

Additionally, NASA and the United Nations Environment Program (UNEP), working with the Department of State, have established a Global Resource Information Database system (GRID).

Separation of Science and Policy

The key lesson learned from the chlorofluorocarbon (CFC) - ozone issue is that it is vital for there to be a clear separation of responsibilities between the scientific agencies and the policy-makers. It was found essential that:

* there is a clear separation between scientific assessments and policy assessments;

* there is a continuous dialogue between the scientific agencies and the regulatory agencies and policy-makers to ensure that the scientific information that is required for decision making is obtained and presented in a digestible form;

* the participants of the scientific assessments are the best scientists in the world and are also representative of the international scientific community;

* the scientific research programs are developed and implemented by the scientific agencies in concert with the scientific community, including the National Academy of Sciences (NAS) and other advisory bodies;

* there is close coordination among the scientific agencies charged with conducting scientific research.

The NASA Upper Atmosphere research program on ozone is closely coordinated with related research programs in other federal agencies, as well as with research programs conducted abroad, and with a good understanding of the requirements of the Environmental Protection Agency (EPA). A comprehensive research program has been developed by these scientific agencies in concert with the scientific community. The program is responsive to the short term needs of the policy-makers, and it also recognizes the need to study more speculative and complex aspects of the issue deemed to be scientifically important.

There are two reasons why the U.S. scientific community were able to be responsive to the challenge of understanding the underlying cause(s) of the Antarctic ozone hole:

* a broad research program was structured that developed sophisticated techniques for in-situ and remote observations from balloons and aircraft to study many topics related to the CFC-ozone issue.

* a stable, vigorous, long-term program for studying atmospheric ozone was supported by the Federal Government

If the atmospheric research programs of NASA, NOAA, and NSF had not had a long term commitment to a broad research program with involvement of the scientific community in government laboratories, universities, and private industry, it is highly likely that we would not have been able to detect or understand the cause of the Antarctic ozone hole for years to come. This is an important lesson for the U.S. Global Change Program, which encompasses a larger suite of global change issues and involves a larger number of federal agencies. Policy directed programs are generally focussed on the policy needs of today, with a limited vision of related longer term scientific issues, and often risk being viewed as intellectually too restrictive to attract the best scientific minds to participate.

In addition to scientific research, NASA is also responsible for providing biennial reports to the Congress and to concerned regulatory agencies on the status of upper atmospheric research, including scientific assessments of potential effects of human activities on the atmosphere, and particularly on stratospheric ozone. Since 1980 the scientific assessments have been cosponsored with other U.S. scientific agencies and international scientific agencies such as the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). The scientific assessments have been conducted and written by the best scientists in the world.

The decision not to conduct national scientific assessments but to conduct international scientific assessments was a vital element in the successful development of the Montreal protocol. The international ozone assessments have been heralded by both scientists and policy-makers as an essential component of the development of both science (identifying areas of scientific uncertainty) and policy. It was essential that all nations used the same scientific basis for policy formulation. As in the case of ozone change, there will be a need to maintain a long-term commitment to a broad Global Change research program. The U.S. Committee on Earth Sciences is an effective forum to ensure that such a commitment is maintained.

The IPCC Scientific Assessment of Climate Change

There is now underway an international assessment of the climate change issue being run by the International Panel on Climate Change. There are three international working groups; a science assessment headed by the UK with strong U.S. participation, an impacts assessment headed by the USSR, and a response assessment headed by the USA. The science assessment will be comprehensive, with broad international participation including the developing countries. It will be built upon previous national and international scientific assessments, and will be peer reviewed by the international scientific community. The science assessment document will have eight chapters as outlined below:

Chapter 1: Changes in Climate Forcing Functions
Chapter 2: The Relative Importance of Climate Forcing Elements
Chapter 3: The Earth's Climate: Changes and Variability
Chapter 4: Processes and Modelling
Chapter 5: Model Simulations of Past and Present Climate
Chapter 6: Model Predictions of Climate Change and their Uncertainties
Chapter 7: Sea Level Rise
Chapter 8: Ecosystem Dynamics and Interactions with the Atmosphere

The assessment will be completed by mid 1990 prior to the Second World Climate Conference. As this international assessment proceeds, NASA will coordinate with the other CES agencies and continue to build its earth science program towards the needs defined by its own Earth System Sciences Committee, by the White House OSTP/FCCSET/Committee on Earth Sciences, by the NAS/NRC Committee on Global Change, and by the ICSU International Geosphere/Biosphere Program.

NASA Research Programs Related to Global Change

The principal activities that comprise nearly all NASA research programs include: (1) the development and deployment of precursor and satellite-based observing systems; (2) the collection, processing, and analysis of satellite and aircraft observations; (3) the development and application of techniques for extracting parameters from remote (satellite and aircraft based) measurements; (4) field experiments, where observations are made from surface, aircraft, and balloon platforms, usually to validate or support the satellite observations or technique development activities; (5) process oriented studies; (6) the theoretical analysis and numerical modelling of physical processes affecting global change processes; and (7) archiving and dissemination of data and information.

The classical manner in which the NASA Earth sciences program has been described is by traditional scientific discipline, i.e.;

1. Atmospheric Chemistry
2. Atmospheric Dynamics and Radiation Research
3. Oceans Research
4. Land Processes
5. Interdisciplinary Research
6. Flight Projects
7. Advanced Development including The Earth Observing System (Eos)

However, a more integrated way to present the NASA program is by the seven interdisciplinary science elements as defined by the Committee on Earth Sciences in the

President's FY1990 Global Change Initiative. These elements and the NASA focussed and contributing research currently conducted in these areas are summarized below.

Element 1---Biogeochemical Dynamics

An essential element of predicting climate change is understanding changes in the atmospheric abundance of the radiatively active gases such as CO_2, CH_4, N_2O, the halocarbons, organic compounds, and sulfur and nitrogen species. This will require an improved understanding of (i) the geophysical and biological processes that control the fluxes of these gases into and out of the atmosphere, from the aquatic and terrestrial biosphere, the areal extent of each ecosystem, and how the geophysical and biological processes and the areal extent of the ecosystems might be altered with a changing climate; (ii) how the fluxes of nutrient species (C, N, S, and P) within, and between, ecosystems are controlled today, and with a changed climate, because it will influence biological productivity and hence the fluxes of trace gases into, and out of, the atmosphere; and (iii) the atmospheric transformation processes of these gases which control their atmospheric lifetimes and hence abundances. While policy options may exist for controlling the atmospheric abundances of gases such as the CFCs and CO_2, they do not exist for gases such as CH_4 and N_2O because the underlying cause(s) for their current increases are not known.

NASA's program in this area consists of:

Research:

* Earth Observing System (Eos): Development of technology to measure from integrated polar-orbiting platforms all aspects of the biogeochemical cycles, including: Ocean primary productivity, atmospheric constituents and energy inputs, land surface characteristics.

* Trace Gas Fluxes from Ecosystems and their Fate in the Troposphere: Use of remote-sensing and in situ methods to measure and model the emissions of radiatively and photochemically important trace gases from ecosystems, and their chemistry and transport in the troposphere.

* Tropospheric Chemical Processes: Measurements of fluxes of trace chemicals into the boundary layer, the study of the processes that mix these gases into the upper free troposphere, and their subsequent chemical transformation processes.

* Stratospheric Processes: Laboratory studies, field measurements (ground-based, aircraft, and balloon), and theoretical analyses relating to the chemistry and physics of the Earth's upper atmosphere and its susceptibility to change, especially ozone.

* Upper Atmospheric Research Satellite (UARS): Utilization of satellite remote sensing instrumentation to study the coupled chemistry, dynamics, and energy inputs to the Earth's stratosphere and mesosphere.

* Ecosystem Processes: Use of remote sensing to estimate vegetation canopy composition and structure, to infer nutrient cycling rates, to infer fluxes of elements to and from ecosystems, and to drive models of ecosystem productivity and biogeochemical cycling.

* Ocean Productivity: To utilize spaceborne ocean color observations to estimate the primary productivity of the global oceans.

* Sea-WiFS Implementation: To initiate a joint venture with EOSAT to develop an improved ocean color scanner (Sea-WiFS) for flight on Landsat-6 in 1991.

* Payload development: To develop, test, and evaluate Earth remote sensing instruments and systems for the measurement of atmospheric constituents, energy input, and land surface characteristics.

* Aircraft operations: Testbeds for future satellite instruments to measure atmospheric chemical composition and land surface characteristics, as well as vehicles for special field projects such as:

- Atmospheric processes: Global Tropospheric Experiments and Polar Ozone Expeditions.

- Canopy Chemistry. High spectral resolution reflectance data from the Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) to estimate vegetation canopy lignin, nitrogen, and chlorophyll concentrations.

- Areal Extent of Wetlands. Remotely sensed estimates, using aircraft optical and radar sensors, of the areal extent and seasonal inundation dynamics of wetlands for use in extrapolating point measurements of trace gas fluxes to larger scales.

Observations

* Tropospheric and Stratospheric Monitoring: Ground-based in situ monitoring of source gases (Global Atmospheric Gases Experiment) and remote sensing of stratospheric chemical composition (Network for the Detection of Stratospheric Change).

* Vegetation Process Monitoring: Advanced Very High Resolution Radiometer (AVHRR) data, both vegetation index and thermal data, are being compiled to understand global patterns of productivity, fire, and land cover change.

* Satellite Measurements and Data Analysis of atmospheric ozone: (Total Ozone Mapping Spectrometer (TOMS)) and other constituents (including atmospheric aerosols) from existing satellites (e.g. Nimbus 7), and analysis of data from Shuttle Imaging Radar (SIR-B) mission for the areal extent of wetlands.

Data Management

* CZCS Data Archival: To process, archive, and distribute global ocean color data from the color scanner (CZCS) which flew on the Nimbus-7 satellite.

* Information Systems: Funding for continued operation of scientific computing resources and data archives in support of all NASA Earth science and application activities, including study of biogeochemical cycles.

Element 2---Ecosystems Dynamics

It is vital that we improve our current understanding of how the productivity and distribution of terrestrial and aquatic species will respond to a changing climate, especially in an period when other factors may be changing, e.g. atmospheric carbon dioxide abundances, ultraviolet radiation levels, the chemical composition of precipitation, and tropospheric ozone concentrations. Changes in the areal extent and productivity of ecosystems will have several affects on the climate system, including: (i) changes in

regional hydrological cycling; (ii) biogeochemical dynamics including the fluxes of trace gases into and out of the atmosphere; (iii) the exchange of energy and water with the atmosphere; and (iv) albedo. Policy response strategies will require an improved understanding of how both agricultural and natural ecosystems will change.

NASA's program in the area consists of:

Research

* Earth Observing System (Eos): Development of technology to measure from integrated polar-orbiting platforms quantities important to land and ocean ecological systems, including: Surface temperature, surface humidity, primary productivity, radiation and leaf area, vegetation type, soil moisture, and evapotranspiration.

* Landscape Dynamics. Large-scale land cover mapping and inventory; use of satellite imagery to document vegetation patterns on the terrestrial landscape and to analyze change over time.

* Ecosystem Structure and Composition. Investigation of the basic biophysical and biochemical determinants of reflected, emitted, and backscattered radiation for use in interpreting remotely sensed data of ecosystem dynamics.

* Ecosystem Modeling. Development of realistic simulation models of ecosystem processes (including production, decomposition, nutrient cycling, evapotranspiration, and succession) which can be driven with remotely sensed inputs.

* Payload development: To develop, test, and evaluate Earth-viewing remote sensing instruments and systems to obtain data for and to develop the techniques for land remote sensing research, including terrestrial ecosystems.

* Aircraft Operations:

- Landscape Pattern. Use of both active and passive airborne sensors covering all useful portions of the electromagnetic spectrum for measuring the spatial distribution and areal extent of terrestrial ecosystems on local to regional scales.

- Vegetation Structure. Radar, laser, and bidirectional passive optical observations of ecosystems to measure or infer such structural properties as canopy height, branch and leaf orientation or distribution, stand density, leaf area index, and, in some cases canopy species composition.

- Energy Balance of Vegetated Surfaces. Airborne thermal sensors for measuring surface temperature to use in calculations of evapotranspiration; bidirectional reflectance measurements to more accurately estimate the albedo of vegetated surfaces.

Observations

* Global Vegetation Patterns. Preparation (processing and compilation) of monthly averaged, global Advanced Very High Resolution Radiometer (AVHRR) vegetation index data for the period 1981-present.

* Regional Observations. Preservation and analysis of fine spatial scale Landsat and SPOT data for selected, climatically sensitive regions of the globe.

Data Management

* Global Vegetation Index. Preservation and archiving of monthly averaged, global AVHRR vegetation index data for the period 1981-present.

* Landsat Browse Facility. Archival and distribution of historic, non-commercial Landsat MSS and TM data are being provided by a NASA Landsat browse facility.

Element 3---Physical Climatic and Hydrologic Systems

An accurate prediction of the magnitude and timing of a change in climate (changes in the patterns of temperature, precipitation and severe weather) is limited because of a significant number of uncertainties in our understanding of the physical climate system, including: (i) how the extent and distribution of clouds may respond to a change in the radiative forcing of the atmosphere, or a change in the aerosol loading of the troposphere; (ii) how the exchange of energy and trace gases between the ocean and the atmosphere may change, especially if the circulation patterns of the ocean change; (iii) how the exchange of energy, and trace gases will be impacted by changes in albedo (due to changes in land cover, and the extent of sea and land ice) and terrestrial vegetation; and (iv) how the climate and hydrologic cycle will interact.

NASA's program in this area consists of:

Research

* Earth Observing System (Eos): Development of technology to measure from integrated polar-orbiting platforms all aspects of the physical climate system, including: Earth radiation budget; surface temperature (land & ocean); winds; atmospheric temperature and water vapor; atmospheric aerosols; cloud properties and cover; precipitation rate; ocean circulation and waves; sea ice extent, character, and motion; snow and ice extent and character; surface soil moisture and wetlands extent.

* Detection of Changes and Identification of Forcings Due to the Greenhouse Effect in the Climate System: Critical analysis of current satellite data sets of geophysically relevant parameters in order to quantify whether there has been any observed changes in the climate system.

* Role of the Hydrologic Cycle in Atmosphere-Surface Interactions: Use of remote sensing to assess the spatial and temporal patterns of the components of the hydrologic and climatic processes that control the forcings and the fluxes between the surface and the atmosphere at the regional and global scale.

* Remote Sensing Techniques: Develop improved and advanced techniques for remotely sensing important atmospheric parameters.

* Regional climate studies: Research on global climate record as well as case studies of drought/flood using conventional and satellite observations in models.

* Global Scale Weather Process Studies. Use of satellite-derived data and modeling to develop a better understanding of the processes which maintain the atmospheric general circulation and which result in the variability commonly called "weather".

* Regional Studies of Hydrologic Cycle Components: The conduct of major field experiments to study land surface/vegetation/ atmosphere interactions.

* Hydrologic Cycle in Land-Atmosphere Interaction: Studies of the states and dynamics of components of the hydrological cycle with the aid of remote sensing.

* Biosphere Contribution to Atmosphere Circulation: The conduct of retrospective analysis of satellite data and field experiments for assessing the role of the biosphere in regional and global atmospheric circulation.

* General Circulation Models (GCM): Development of GCM's that allow simulation of regional and global atmospheric patterns and processes, with an emphasis on the role of the biosphere.

* Ocean Circulation & Air-Sea Interaction: To utilize spaceborne scatterometer and altimeter observations to estimate the surface wind stress and topography of the global oceans.

* Sea Ice & Ice Sheets: To utilize spaceborne radar and radiometer observations of the polar regions to estimate sea-ice cover and ice-sheet topography.

* Ocean Topographic Experiment (TOPEX/POSIDEN): To implement a dedicated altimeter mission to observe the surface topography of the global oceans with sufficient accuracy to enable a determination of the mean and variable circulation, as well as the tides.

* NASA Scatterometer (NSCAT): To implement a scatterometer sensor to observe the surface roughness of the global oceans with sufficient accuracy to enable a determination of the surface wind stress field.

* Aircraft Operations: Operation and support for aircraft used in the operation of instruments to measure land surface climatology, atmospheric variables, cloud climatology, and other important aspects of the climate and hydrological system.

- Land Surface Climatology: Airborne sensors to provide an intermediate scale of observation to that of ground and satellite sensors for measurement of surface temperature, moisture conditions, vegetation index, and for estimation of mass and energy exchanges between the land surface and the atmosphere.

- Regional Land Surface Hydrology. Airborne passive microwave observations of soil surface water content, of surface water flows and drainage patterns, and of snow extent, depth, and its equivalent water content are used to study the storages and fluxes of water within the land components of the hydrologic cycle.

Observations

* Cloud- Radiation Processes: Satellite, airborne, and surface-based observations of cloud cover and radiative properties, data analysis and modeling.

* Global Hydrological Processes: Passive microwave observations from the DMSP satellite series to provide an archive of the climatology of global precipitation, atmospheric moisture, oceanic evaporation, ocean wind stress, and soil moisture.

* Regional and Global Surface Hydrology: Airborne, space-based and surface-based observation and analysis of soil water content and snow depth and its equivalent water content.

* Mission Operations and Data Analysis (MO&DA): Provides for the extended operations, data processing, validation, and data analysis of spaceborne missions which observe the Earth radiation budget, land surface climatology and hydrology, and atmospheric water vapor.

Data Management

* Pilot Climate Data System(PCDS): The data made available through the PCDS include key earth radiation budget parameters such as albedo, solar radiation, and thermal radiation as well as sea ice coverage, clouds, and aerosols.

* International Satellite Cloud Climatology Project (ISCCP): The ISCCP involves the collection and processing of the cloud images acquired by the international network of operational meteorological satellites.

* DMSP/SSMI Data Archival: To process, archive, and distribute DMSP/SSMI-derived estimates of surface wind speed and sea-ice cover.

* Geosat Data Archival: To process, archive, and distribute Geosat-derived estimates of ocean and ice-sheet topography.

* Pilot Land Data System (PLDS): Development of a data and information system consisting of three main nodes that will provide access to airborne, satellite, and surface-based data sets acquired by NASA and its land scientific research community.

* International Satellite Land Surface Climatology Project (ISLSCP): The First ISLSCP Field Experiment (FIFE) information system has been developed to collect, process, and archive surface-based, airborne, and satellite data for assessing land-surface and atmosphere interaction at the mesoscale level and for validating satellite observations of land surface properties.

* Alaska SAR Facility (ASF): To implement a capability to receive, process, archive, and distribute synthetic aperture radar observations of polar ice cover from European, Japanese, and Canadian satellites.

Element 4---Human Interactions

An analysis of how human activities have changed the climate forcing functions in the past would contribute to an understanding of how the Earth's system has changed because of human activities compared to it's natural variability. This would include an analysis of: (i) major land-use changes; and (ii) which human activities have directly, or indirectly changed the fluxes of radiatively active trace gases. Projections of future changes in both land-use patterns and the emissions of radiatively active trace gases into the atmosphere are a vital input to theoretical model predictions of future climate states. The most probable future industrial release rates of gases such as the CFCs, Halons, N_2O, CO, and CO_2 depend upon economic, social, and political factors. Another key set of questions which need to be addressed include: How will changes in regional and global climate impact energy, agricultural, natural resource, coastal zone management, and water resource policies.

NASA's program in this area consists of:

Research

* Acid Deposition Effects. Remotely sensed observations and analysis of forest decline associated with air pollution and acid deposition.

* Tropical Deforestation. Use of satellite data to monitor large-scale deforestation and to observe the frequency, extent, and role of fires in tropical forests.

* Desertification. Use of historic satellite data to study change in vegetation cover and extent related to climatic stress and/or land use pressure.

Element 5---Earth System History

Two key questions that are currently being asked are: (1) Is the Earth's climate currently changing, and is it outside of expected natural variability? and (2) What is the reliability of the predictive models? To answer the first question requires a quantitative measure of the natural variability of the Earth's climate over both short, decades to centuries, and long, millennia, time periods. The natural variability of the Earth's environment over long time scales can be deduced using a number of indicators, including tree rings, ice cores, deep sea cores, terrestrial and marine sediments, and geomorphic features. This historical record of the Earth's environment can also be used, within limitations, to test our ability to rationalize how the Earth's system should have responded to changes in the climate forcing functions on timescales of decades to centuries.

NASA's program in this area consists of:

Research

* Evolution of Continents: To use remotely sensed observations of the Earth's surface to investigate the history and evolution of the continents from early formation through the present.

* Quaternary Processes: To use remotely sensed observations of the Earth's surface to investigate Quaternary geologic processes, to document the course of recent geomorphic, volcanic, and climatic processes, and to understand their role in the formation of the present land surface.

* Technique Development: To develop remote sensing techniques for studying geologic processes at regional and global scales.

* Aircraft Operations :

- Structure and Composition. Use of multi-sensor (visible, near and shortwave infrared, thermal infrared, and microwave) airborne observations for structural and compositional mapping of the Earth's surface to provide information on the geologic processes responsible for the evolution of the continents.

- Surface Geomorphology. Use of both active and passive airborne sensors, including laser altimetry, and covering all useful portions of the electromagnetic spectrum

for measuring surface roughness, composition and landforms from which are inferred the recent geologic, volcanic, and paleoclimatic processes that shaped them.

Element 6---Solid Earth Processes

Understanding the contribution of solid-Earth processes to changes in the atmospheric abundance of radiatively or chemically active gases would contribute to understanding one cause of natural variability in the climate system. This would require an improved understanding of the magnitude and frequency of injection of trace gases into the atmosphere from volcanoes.

NASA's program in this area consists of:

Research

* Earth Observing System (Eos): Development of technology to measure from integrated polar-orbiting platforms to measure solid earth processes such as plate motion, surface topography, and land surface composition.

* Volcanism and Recent Tectonics: To use remotely sensed data to document the distribution of current volcanic activity and recent volcanic deposits and study volcanic processes in order to develop a better understanding of contemporary volcanism-related earthquakes and volcanic eruptions.

* Tectonic Plate Movement and Deformation Processes: Develop an understanding of the solid Earth, particularly the processes that result in movement and deformation of the tectonic plates.

* Earth's Rotational Dynamics Processes: Develop models of polar motion, Earth rotation, and dynamics of the Earth's interior.

* Geopotential Field: The goal is to develop high resolution, extremely accurate, truly global gravity and magnetic fields to meet the requirements of geodesy, oceanography, orbit determination and related disciplines.

* Aircraft Operations:

- Plate Tectonics and Continental Evolution. Multi-sensor aircraft observations of surface structure and lithology and of the mineral composition of exposed rocks to infer the accretionary, depositional, tectonic, and deformational processes which shaped today's continents.

- Surface Mineral Composition. High spectral resolution reflectance data from the Airborne Visible-Infrared Imaging Spectrometer (AVIRIS) to uniquely identify surface minerals and thereby infer the processes that emplaced them.

- Laser Altimetry. Precise measurement of surface topography using an airborne laser profiler to elucidate structural relationships and document surface topography.

Observations

* Laser Ranging: Precise laser ranging measurements to and from satellites and the Moon for Studies of the solid Earth.

* Very-Long-Baseline Interferometry: VLBI measurements of baseline lengths and Earth orientation.

* Global Positioning System: Use of GPS signals to measure crustal movements.

* Satellite Gravity Measurements: Use of laser ranging, satellite orbital studies, radio Doppler, drag-free satellite technology, and satellite altimetry for Earth's gravity field studies.

* Magnetometer Field Measurements: Use of satellite magnetometers to measure the intensity and direction of Earth's magnetic field to yield insight into core fluid dynamics, core-mantle boundary interactions, and deep crustal structure and composition.

Data Management

* Crustal Dynamics Data Information System: Management of observational and reduced data for solid Earth studies.

* Pilot Land Data System (PLDS): Development of a data and information system consisting of three main nodes that will provide access to airborne, satellite and surface-based data sets for geologic test sites acquired by NASA and its land scientific community.

Element 7---Solar Processes

It is essential to improve our understanding of the short (27 day solar rotation) and long-term (11 / 22 year sunspot cycles) variability in the output of the sun, both total irradiance and flux as a function of wavelength. Solar variability is a major contributor to natural changes in the radiative balance and the chemical composition of the atmosphere. Hence, it is important to monitor, and understand the impact, of solar variability on the climate system.

NASA's program in this area consists of:

Research

* Earth Observing System (Eos): Development of technology to measure from integrated polar-orbiting platforms to measure solar output, both of the total energy output and for specific wavelength regions (particularly ultraviolet).

* Payload and Instrument Development: Development, testing and operation on Shuttle missions (Atmospheric Laboratory for Applications and Science-ATLAS) of an active cavity radiometer to measure total solar output (solar constant).

* Upper Atmosphere Research Satellite (UARS): Obtain wavelength-resolved measurements of the solar spectrum between 115 and 430 nm.

Summary

Significant progress has been made in our understanding of the physical and chemical processes that control the distribution of ozone and the temperature structure of the atmosphere. However, we must recognize that significant uncertainties in our knowledge remain, and that these can only be resolved by a vigorous program of research. Given what we know about issues such as the ozone and greenhouse warming we should recognize that we are conducting a global scale experiment on the Earth's atmosphere without a full understanding of the consequences. The Antarctic ozone phenomenon vividly demonstrates that the environment does not always change slowly, linearly, or predictably in response to a perturbation.

Understanding these and related issues in global change should clearly be a priority for the scientific and policy communities. This will require a comprehensive coordinated national and international research effort. Wise policy decisions require an improved understanding of the way in which the Earth's environment varies naturally and in response to human activities.

In particular, the Committee on Earth Sciences has been a successful mechanism to develop an effective and well-coordinated Federal research effort and to collaborate closely with related national and international activities. The CES research plan will provide an important "blueprint" of how to improve our understanding of the way in which the Earth's environment varies naturally and in response to human activities. This improved scientific understanding is critical to wise policymaking.

Satellite data, if well calibrated and continuous, can provide the data sets required to document and understand global change. At present the ability to measure many of the needed ocean, land, and atmospheric parameters has been demonstrated. However, there are presently very few global data sets, satellite or ground-based, of the quality and length necessary to contribute to documenting global change. If we wish to have available in the future a documented data-base of global change, we must begin now to establish those systems that will obtain the required comprehensive data. NASA is firmly committed to working closely with all other Federal agencies and international organizations.

TESTIMONY
April 19, 1989

on

CLIMATE CHANGE AND AGRICULTURE

before the

Subcommittee on Department Operations, Research, and Foreign Agriculture

and the

Subcommittee on Forests, Family Farms, and Energy

of the

House Committee on Agriculture

by

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Table of Contents

	Page
Definition of the problem	2
Review of general organism responses	3
Review of known plant responses	5
Some uncertainties	6
Net carbon fixation	6
Water loss and water-use-efficiency	6
Increased tolerance to toxic air pollutants	6
Increased tolerance to salinity	7
Changing disease tolerance of plants	7
Increased nitrogen fixation and mycorrhizal activity	7
Changing competition between weeds and crops	7
Effects of changing nutritional quality on insects	7
Summary Statement	8
References	9

CLIMATE CHANGE AND AGRICULTURE

Definition of the problem.

First I would like to clarify an aspect of the effect of climate change on agriculture that is not well understood.

All organisms respond to changes in environment. Agricultural species, and all other species of earth, have environmental requirements, tolerance ranges and lethal points and respond accordingly when the environment changes.

Environment is made up of many factors; some physical, some chemical, and some biological. Physical and chemical environmental factors are termed abiotic as opposed to biotic factors associated with life.

Climate is the historical pattern of a selected set of abiotic environmental factors. Temperature, precipitation and periodicity of events are paramount features of climate. Not all environmental factors controlling life, however, are routinely included in the traditional suite of variables called climate. Soil minerals, atmospheric gases, water quality, ultra-violet light, and people are dominant environmental factors never considered in climate reports.

All of the abiotic and biotic environmental factors mentioned above are changing on a global scale. Humans are a primary reason for this global change. Fossil fuel consumption is releasing billions of tons of carbon dioxide into the global atmosphere annually. Industrial wastes are being released into the global atmosphere and the global waters at unprecedented rates. Deforestation and soil tillage are decreasing ground cover, releasing stored organic carbon and changing the energy budget of the earth.

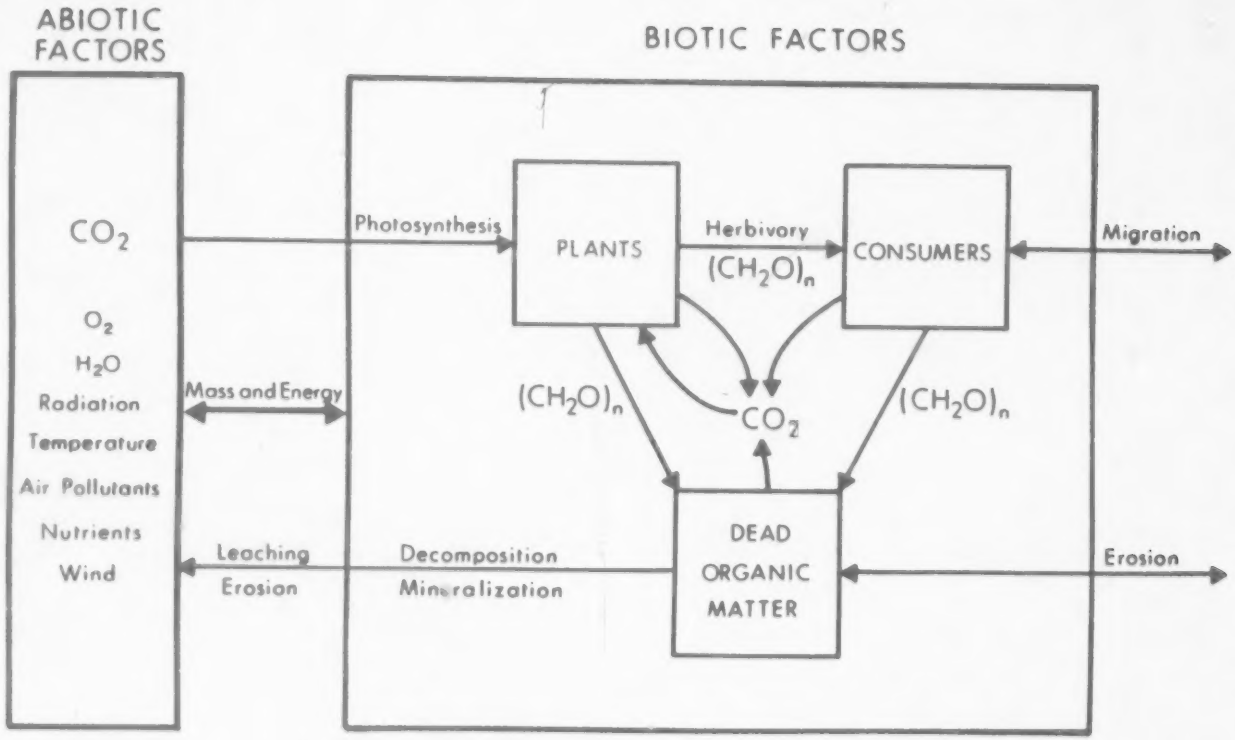
Climate is only one aspect of global change. Thus, we should not be misled by focusing on climate change alone. We should address global environmental change in all of its essential components as we consider the future of agricultural and cultural development.

Review of general organism responses to the environmental complex.

The distinction laid out above is critical when plant life and agriculture are to be considered. One of the driving features of global environmental change is the enhancement of atmospheric carbon dioxide by fossil fuel consumption. Carbon dioxide is essential to life. The biochemical energy necessary for life is stored in the chemical bonds of organic compounds within green plants. These energy rich compounds then pass from organ to organ within plants and from organism to organism within living systems. At each transfer point, carbon is returned to the atmosphere as carbon dioxide (CO_2) from respiration. Each of these transfers is regulated by the environmental factors surrounding the organisms.

Some of the important environmental factors known to affect plants are presented in Figure 1. Water, sunlight, temperature and wind are traditional climate factors that affect organisms. They are included on the left hand side of the figure as abiotic factors. Equally important among the abiotic factors, however, are CO_2, air pollutants and soil nutrients. All of these factors affect organisms directly and they all interact to modify the way organisms respond to the traditional climate factors.

No organism exists alone, however. In addition to responding to abiotic factors, organisms respond to each other. All organisms have enemies; weeds, pests, and diseases that greatly affect vigor and survival. Many organisms have symbionts; species that assist each other in meeting the challenges of survival. Some symbionts are so closely associated with each other that they are mutually obligated for survival. If enemies or symbionts are significantly affected by an environmental change, their ecological associates will likewise respond. Some of these biological interactions are represented in Figure 1 as biotic factors.



CARBON CYCLING IN ECOSYSTEMS

Review of known plant responses to environment

Plant responses that are known to be sensitive to CO_2 and associated climate factors were recently reviewed in detail (Strain and Cure 1985). Table 1 is a list of many known plant responses to environmental change. Considerable research (reviewed in an annotated bibliography by Strain and Cure, 1986) has shown the degree and nature of these responses. It is also clear that changes in one or more of the environmental factors will modify responses to the others.

Table 1. Some reported plant responses to CO_2 enrichment and associated environmental variables. (Modified from Strain 1985).

1. Photosynthesis
2. Light respiration
3. Dark respiration
4. Biochemicals produced
5. Growth rate
6. Transpiration
7. Stomatal aperture
8. Tolerance to toxic air pollutants
9. Leaf area
10. Leaf weight/leaf area
11. Leaf age
12. Stem diameter
13. Number of branches
14. Root to shoot ratio
15. Internal cytological changes
16. Date of flowering, fruiting, and seed maturation
17. Number of flowers, fruits, and seeds
18. Size of flowers, fruits, and seeds
19. Change in maturation date
20. Seed and spore germination rate
21. Disease tolerance change
22. Weed tolerance change
23. Insect tolerance change

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Some Uncertainties

Now I would like to focus on a few of the uncertainties remaining in our knowledge. We must understand the issues I will itemize below if we are to predict future agricultural responses to global change. All of them are items deserving of immediate and significant research activity.

Net carbon fixation. The net carbon fixed by plants is expressed by the difference between total photosynthesis and all plant growth requirementss for respiratory energy.

Net Photosynthesis = Total Photo. - Light Resp. - Dark Resp.

Uncertainties in this area derive from evidence that some plants reach lower equilibrated rates of net photosynthesis after total adjustment to enriched CO_2 than plants measured in short-term experiments (DeLucia et al. 1985, Sasek et al. 1985). We do not know if the decline is due to decreasing photosynthetic potential or to increasing respiratory demand. Theoretically, respiration in the light should decrease at high CO_2 because of competition at the carboxylation sites between CO_2 and O_2. There is also relatively recent evidence from Gifford et al. (1985) and new unpublished evidence from Gifford, Burt Drake of the Smithsonian, and Chantal Reid at the Duke Phytotron that dark respiration declines in plants totally adjusted to long-term CO_2 enhancement.

Water loss and water-use-efficiency. Partial stomatal closure with elevated CO_2 (Pallas 1965) frequently is observed which reduces transpiration and increases the efficiency of water use. Although Idso and Quinn (1983) hypothesized this effect would result in a reduction in water use by plants in arid regions and that this would result in improved hydrological yield and plant productivity, Kimball and Idso (1983) in that same year demonstrated that increased leaf area, frequently observed in crop response to CO_2, would lead to increased water loss and no improvement in soil water status.

Increased tolerance to toxic air pollutants. Increasing CO_2 closes stomata as described above increasing resistance to the penetration of gaseous air pollutants into leaves and decreasing damage by ozone (Coyne and Bingham 1977) and SO_2 (Carlson and Bazzaz 1982). This phenomenon is

more completely discussed by Dahlman et al. (1986) who point out that these studies were short-term and have not been repeated.

Increased tolerance to salinity. Two studies have shown that CO_2 enhancement increases the tolerance of plants to soil salinity (Schwarz and Gale 1984, Bowman and Strain 1987). Bowman and I proposed that increased carbohydrate content in the root systems of CO_2 enhanced plants allows more root respiration and consequently more energy for active ion exclusion but this work has not been pursued.

Changing disease tolerance of plants. The journal "Phytopathology" is replete with articles on increasing virulence of plant pathogens under increased temperature and humidity conditions. Thus, we may see changing disease problems in agriculture and climate in areas of increasing moisture but decreasing disease incidence in areas becoming drier.

Increased nitrogen fixation and mycorrhizal activity. Many plant-microorganism interactions associated with increased plant productivity have been described (Marshall 1977) and, therefore, we should expect to see such changes if CO_2 increases photosynthesis. Current studies on mycorrhizae at Oak Ridge National Laboratory by Luxmore and colleagues and on nitrogen fixing bacteria in legumes by Richter and colleagues at the Duke Phytotron indicate an interaction.

Changing competition pressures between weeds and crops. In USDA funded studies at the Duke Phytotron, David Patterson and colleagues have shown changing relationships among C3 and C4 weeds and crops (Patterson and Flint 1980, 1982; Patterson et al. 1984; Patterson 1986). All of these studies suggest that C3 plants will outcompete C4 plants in the future. Based on theoretical considerations of basic differences in CO_2 saturation of photosynthesis between these two photosynthetic pathways, Akita and Moss (1972) predicted this result. Interactive studies with water stress and different stages of plant development, however, have raised new questions about the realization of competition in the field, away from the optimal conditions of the laboratory (Wray and Strain 1986,1987a and b). The introduced weedy vines Japanese honeysuckle and kudzu both become more aggressive under CO_2 enrichment (Sasek, unpublished Ph.D. dissertation).

Effects of changing nutritional quality of plants on insects. Carbon dioxide enrichment generates leaf tissue relatively high in carbon relative to nitrogen and phosphorus (Lincoln et al. 1984). The resulting C/N or C/P ratios affect the feeding efficiency of insect pests (Lincoln et al. 1984, 1986). The net effect of declining feeding efficiency in Lincoln's experiments has been an increasing rate of leaf removal by feeding larvae.

Summary Statement

All organisms respond to environmental changes. Each species, in fact each variety of plant, microbe, and animal responds to the environmental complex in its own unique way. This differential response ensures that some genotypes will be benefited by some environmental changes and detrimentally affected by others. Organism interactions, e.g. competition, herbivory, pollination, will change through time as environmental factors change.

We can not predict all of the environmental factors that will change in the future. We can not predict adequately how long the current environmental "problems" will be with us. In the case of climate change, we can not yet predict the magnitude of change to occur nor the rate of change. In some cases, we are still uncertain whether changes will be positive or negative in sign, or if they will happen at all.

We can be certain, however that global environment will change in the future. It is imperative that we develop a capability to predict future global change and that we have a research capability for the continuing examination of global change and its consequences. The USDA is encouraged to participate fully in the analysis.

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Addendum to the testimony of Boyd R. Strain

I would like to modify my previously submitted testimony by the addition of the attached published review paper. The paper, entitled "Direct Effects of Increasing Atmospheric CO_2 on Plants and Ecosystems" by Boyd R. Strain, was published in the January 1987 issue of the scientific review journal Trends in Ecology and Evolution.

In summary, this paper states that the long-term biological effects of allowing the concentration of CO_2 in the global atmosphere to double by the middle of the next century are not yet predictable. Increasing the concentration of CO_2 in the air will almost always increase net photosynthesis and plant growth if other environmental factors are maintained optimally. The CO_2 response can not be obtained, however, if other environmental requirements are not satisfied.

In an agricultural context, this means that soil fertility, available soil water, and crop cultivars will have to be manipulated to take advantage of increasing CO_2 fertility. Since each plant species responds uniquely to environment, it will be a continuing and increasing problem to develop the best crops and the appropriate agrotechnology to maintain an improved yield.

In less managed ecosystems (e.g. rangelands and forests) where floristic balance is currently maintained by competition among species, increases in vigor of one species can be expected to affect detrimentally the other species. Plants that photosynthesize by the C3 pathway will outgrow C4 competitors as CO_2 continues to increase. Plants of improved water use efficiency (less evaporation) in dry areas may begin to displace competitors which maintain high evaporation rates and become water stressed.

In addition to changing plant responses and subsequent changes in plant-plant interactions, plant-animal and plant-microbe interactions can also be expected to change. The nitrogen content of leaves has been shown to decrease relative to carbohydrate content when plants are grown at high CO_2. This decrease means that the plant tissue is less nutritous. It has been shown that this decrease will affect plant eating insects causing them to eat more leaf tissue to obtain adequate growth rates. Microbial decomposition also slows as nitrogen to carbohydrate content decreases in tissues.

TREE vol. 2, no. 1, January 1987

Direct Effects of Increasing Atmospheric CO_2 on Plants and Ecosystems

Boyd R. Strain

The long-term effects of allowing the concentration of CO_2 in the global atmosphere to double by the middle of the next century are not yet predictable. However, it is inevitable that there will be a change in climatic and ecological patterns. Increasing the atmospheric CO_2 concentration under experimental conditions has been shown to alter the growth rate and reproductive potential of plants, and must ultimately affect interactions at the community level and beyond.

There is now compelling evidence that the carbon dioxide concentration of the global atmosphere is increasing[1]. From a pre-industrial concentration of approximately 270 parts per million (p.p.m.), the mean global concentration of CO_2 rose to 345 p.p.m. by 1984[1]. The primary causes of this are the burning of fossil fuels[2] and deforestation[3]. Estimates of future CO_2 emissions and the concentrations expected to accumulate in the atmosphere vary greatly, but there is now a consensus that the global atmosphere will reach a mean of 600 p.p.m. CO_2 by the year 2050 ± 20 years[4,5].

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CO_2 and climate

Carbon dioxide is a radiative gas with the potential to affect the earth's energy budget[6]. The contemporary surface air temperature at land stations is already 0.5 ± 0.2°C warmer than the pre-industrial value[7]. Other radiative gases are also increasing in the global atmosphere[8]; these trace gases (including methane, various chlorofluorocarbons and nitrous oxide) combined have the potential to equal the global warming effect of CO_2 (Ref. 9).

Future increases in radiative gases in the atmosphere will change the overall climate[10]. A recent review of model predictions[11] concluded that the mean global surface temperature will be 3.5–4.2°C warmer than at present by the time atmospheric CO_2 concentration doubles. This represents a significant reduction in variability of predictions from earlier global circulation models, most of which predicted increases in the range of 1.5–4.5°C (Ref. 10). Estimates of future global increases in precipitation[11] accompanying a doubling in atmospheric CO_2 range from 7% to 11%.

The degree and pattern of climatic change associated with a doubling of CO_2 would have major effects on the plants and animals of the earth[12,13]. If climate regimes alter as projected by the global circulation models[11], major adjustments may have to be made in management decisions in agriculture[14], forestry[15], hydrology[16] and in habitat and species conservation[17].

Biological effects of increasing CO_2

There is a large array of direct and indirect biological responses to CO_2 enhancement (Table I)[18]. Increasing the concentration of CO_2 in the air will almost always increase net photosynthesis and plant growth[19]. Plant development rate (and phenology), growth, and tissue nutritional quality also usually change as atmospheric CO_2 concentration increases[20]. Basically, CO_2 is a plant fertilizer. As the availability of CO_2 increases, plants can be expected to respond as conceptualized in Fig. 1, and it is clear that whole ecosystems will also be affected.

Ecosystems will be altered by, for example, differential responses of plant species to CO_2 fertilization[22,23]. In vegetation where floristic balance is currently maintained by interspecific competition, increases in vigor of one competitor can be expected to affect detrimentally the other species. Plants that photosynthesize by the C_3 pathway, for example, will prob-

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TREE vol. 2, no. 1, January 1987

ably outgrow C_4 competitors as CO_2 continues to increase[24].

Ecological responses have not been adequately investigated. However, a major study is under way in the tundra of Alaska[25] with the objective of examining the response of the ecosystem to several years of CO_2 enrichment and simulated climatic warming. Plots of tussock tundra have been enclosed in chambers in which temperature, humidity and CO_2 concentration can be controlled (Fig. 2). Field measurements were conducted throughout the growing seasons of 1983, '84 and '85. Some of the chambers were run at ambient conditions as controls, others enriched with CO_2, and a further set enriched with CO_2 and warmed by 4°C.

The results of these treatments have shown that plants in the field do respond to CO_2 enrichment and that the nature and degree of response is species-dependent. Graminoid species (*Eriophorum vaginatum* and *Carex bigelowii*) responded more in photosynthesis and in vegetative growth than did subshrubs (*Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Ledum palustre* and *Betula nana*). Such differential responses may affect competitive relationships between species and perhaps alter community structure[25].

From many studies of CO_2 enrichment under conditions of variable soil-moisture supply (reviewed in Ref. 25) it is clear that water-use-efficiency increases as CO_2 increases. Basically, increasing CO_2 leads to stomatal closure, causing transpiration to decline while net photosynthesis increases. The decreasing rate of water loss improves overall plant water status, allowing more plant growth during episodes of drought if atmospheric CO_2 remains high. This saving has been estimated to be sufficient to increase water yield in some watersheds[16].

Atmospheric CO_2 increase is also expected to affect the reproductive

Table I. Physiological and ecological aspects of atmospheric CO_2 enhancement. If responses occur in the primary physiological and ecological processes listed, the secondary and tertiary level responses are unavoidable. *From Ref. 18.*

Physiological aspects
Primary physiological responses
- Photosynthesis
- Photorespiration
- Dark CO_2 fixation
- Stomatal aperture

Secondary physiological responses
- Photosynthate concentration
- Photosynthate composition
- Photosynthate translocation
- Plant water status: transpiration, tissue water potential, water use efficiency, leaf temperature
- Tolerance to gaseous atmospheric pollutants

Tertiary whole plant responses
- Growth rate: weight, height, leaf area, node formation, stem diameter, leaf senescence
- Growth form: height, branch number, leaf number, leaf area, root/shoot weight, stem diameter, leaf specific weight (weight/area), cytological and anatomical changes
- Reproduction: flowering time, flower size, flower number, fruiting time, fruit size, fruit number, seed maturation, number of seeds per plant

Ecological aspects
Primary organism interactions
- Plant–plant: interference, competition, symbiosis
- Plant–animal: herbivory, pollination, shelter
- Plant microbe: disease, decomposition, symbiosis (mycorrhizae, N-fixation)

Secondary organism interactions
- Evolutionary effects (genetic differentiation)

Tertiary ecosystem responses
- Feedback effects (integration of all biotic and abiotic interactions occurring through time)

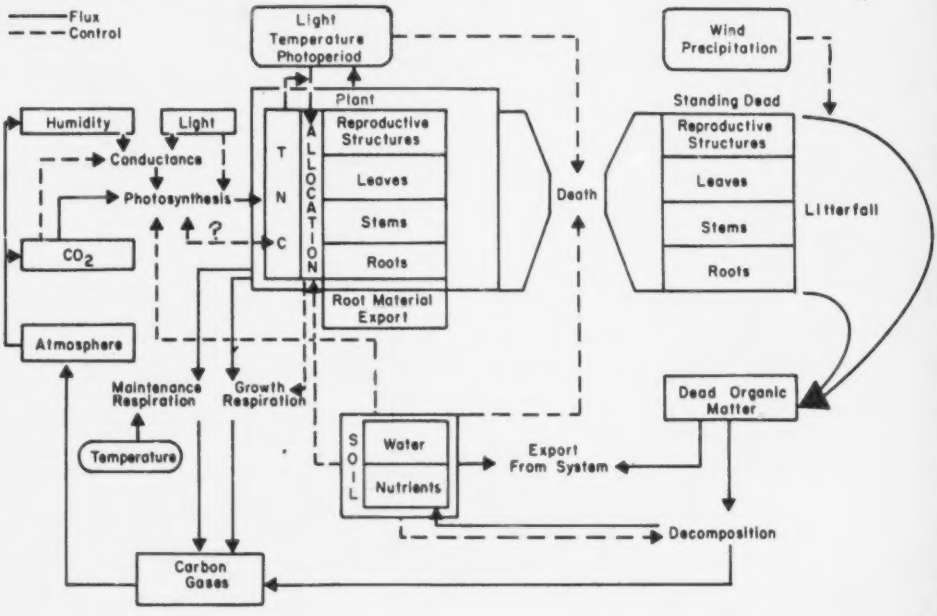

Fig. 1. Major fluxes and controls important in predicting plant growth and ecosystem responses to CO_2 enhancement. TNC denotes total nonstructural carbohydrate. The question mark on the control arrow connecting photosynthesis and TNC implies that we know little about feedbacks from the soluble carbohydrate pools in plants under conditions of elevated CO_2. *Reproduced, with permission, from Ref. 21.*

TREE vol. 2, no. 1, January 1987

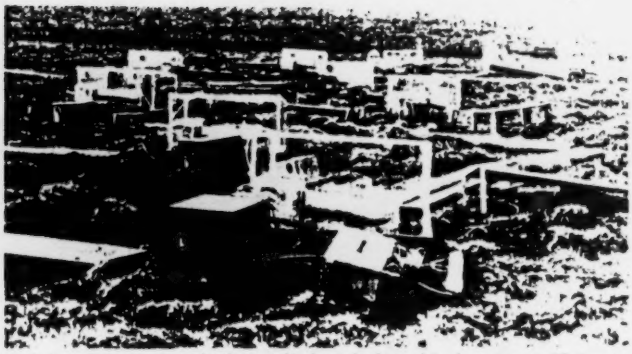

Fig. 2 Controlled environment chambers used in the study of tussock tundra response to CO_2 increase and air temperature warming. See Ref. 25 for a detailed description of the study.

potential of plants and therefore to induce successional and perhaps evolutionary changes in ecosystems[26]. In the most complete study accomplished to date, it was shown that reproductive potential of *Polygonum pensylvanicum* increased as CO_2 increased but that of *Chenopodium album* did not[27]. Other species were intermediate, responding under some soil fertility levels but not under others. Vegetative reproduction is also affected by CO_2 enhancement; more branching, rooting and tiller production has been reported[28].

In addition to changing plant–plant interactions in changing environments, plant–animal and plant–microbe interactions may also change. A study of the feeding response and subsequent growth of the soybean looper (*Pseudoplusia includens*) on soybean leaves produced at different levels of CO_2 in the atmosphere showed that feeding efficiency declined with increasing CO_2 (Ref. 28). Apparently, changes in the carbon to nitrogen ratio in leaf tissue were sufficient to affect feeding efficiency of the insect. More leaf tissue was required by the insects to achieve an equal weight gain as CO_2 level increased. Similar alterations are to be expected in interactions between plants and microbes but little research has been published on how disease or decomposition are affected by atmospheric CO_2 level[29].

Information is needed

Few endeavors could be more important than the study of the ecological and evolutionary effects of another century of complex, but unidirectional, environmental change affecting the entire globe. Most ecological theory has been developed in the context of equilibrium, and stable and climax ecosystems. The dynamic nature of the environment, however, has now become apparent, and concepts of cyclic succession, disclimax and dynamic equilibrium have become commonplace; these concepts assume cyclic environmental change and/or net environmental drift over decades or centuries.

Apart from long-term trends reflected in paleoclimates and the response of organisms to centuries and millenia of net environmental drift, we have no experience upon which to base rational management decisions during the coming decades. In a future of relatively rapidly changing, anthropogenically induced global environmental change, how much change is acceptable? What rate of change can we manage? Can ecological and evolutionary forces maintain a biological resource base appropriate to meet all of the needs of humans? If we decide to allow or to encourage the global environmental change, what features do we monitor to measure the impact? What predictors can we develop to give us early warning about parameters or rates of change that are potentially dangerous to human societies?

There is an increasing awareness of the problem, as was demonstrated at an international meeting in Villach, Austria in 1985 (Ref. 5). Australia[10] and the Netherlands[11] have reviewed the CO_2 issue and published reports, but only the United States has established a national research plan[12]. A review of the global nature of the problem was recently completed by the US Department of Energy and a modeling approach to ecological analysis has been published[13]. Are we doing enough?

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CONSEQUENCES OF CLIMATE CHANGE FOR AGRICULTURE

by

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Introduction

We take as given that it will become necessary to adjust and adapt agriculture to future climate change. Agriculture in developed and developing countries will be challenged to lessen the costs of unfavorable climate changes and to seize the benefits of those that are favorable. How successful countries are in meeting this challenge will determine in large measure their future comparative advantage in agriculture. In this section, we ask how future agriculture might adapt to climate change, taking account of differences between developed and developing countries. We begin with discussion of the agricultural adjustment implications of gradual climate change, then summarize short-term and long-term adjustment options in developing and developed countries, then consider factors that may strongly influence the effectiveness of adjustment and adaptation, and finally suggest broad policy recommendations for fostering adjustment and adaptation.

Changing Agriculture and Changing Climate

Agriculture will undergo major transformations in the coming decades, some linked to climate and others to fundamental technological, socio-economic, and environmental changes. There are no persuasive reasons to believe that global rates of growth in food and fiber capacity will fall behind rates of growth in world demand, climate change or not. A necessary feature of the expected increase in world agricultural capacity is that farmers and agricultural institutions will continually adjust and adapt production to reflect a variety of new technologies and economic conditions. Many such adjustments and adaptations will occur, again, whether climate changes or not. Agriculture has been, and we think will continue to be, flexible and capable of responding to these new challenges.

The probability of success in these responses will be higher if climate change is continuous through time rather than abrupt. There is much uncertainty about this, but we believe that the change most likely will be continuous, although many thresholds of agroclimatic significance, some positive and some negative, may be crossed at different points along the way.

Opportunities for Adjustment and Adaptation

Agricultural responses to climate change can be short or long term. Short-term adjustments are those farmers can make with existing technologies and management practices. Long-term adaptations refer to the development of new management strategies and technologies, and are likely to require significant investments in research. An example is development of new crop varieties, which may take up to 10-15 years in developed and developing countries alike. Long-term adaptation should not be thought of as a single event but rather as a continuous sequence or cycle of events.

Short-term adjustments will be the first response of farmers to climate change. The effectiveness of such adjustments will be tempered by the ways in which farmers respond to climate "stimuli." We argue that study of the effects of climate on production agriculture in both developed and developing countries must take explicit account of the economic environment in which farm firms operate, recognizing that this environment reflects not only local and regional conditions but those at the national and global levels as well. This is to say that the farm enterprise is part of an interconnected system of local, regional, national and world markets.[1]

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1. We argue that purely subsistence farming comprises a small and dwindling share of agriculture in all but the least developed countries. In most developing countries virtually all farmers produce beyond what is needed for subsistence and thus are influenced by market prices. We further elaborate on this below.

In such a system, emphasis is placed on the annual and interannual planning process on the farm. Farmers' expectations of future market conditions for inputs and outputs affect current planning and production decisions. Expectations of climate, other environmental conditions such as water and soil, and government policies also are part of the farm decision framework. The role of the market as a price setting mechanism is important as a determinant both of farm profits and of the mix of farm outputs. Any given farmer is a price taker, i.e., market prices are independent of the level of his or her output. For farming as a whole, however, prices and output are interdependent.

The dynamic nature of the relationship between climate and agriculture is critical to understanding how adjustment will be made. Climate change affects expectations, which then lead to adjustments of production decisions. These adjustments are part of both annual planning cycles and longer term (say 5-10 years) planning decisions.

In many developing countries a large sector of small, poor farmers co-exists with a small sector of large, rich farmers. The decision making framework of the two sectors is similar in the sense that each sector is responsive to changing economic and technical conditions and can be expected to be responsive to changing climatic conditions as well. However, the adjustment options of the small, poor farmers generally are fewer than those available to the large and rich, reflecting their differences in resource endowments, the large and rich farmers having more land, capital and access to information than the small, poor farmers. This difference makes analysis of farmer adjustments to climate change in developing countries more complicated than in developed countries where differences in resource endowment generally are less marked.

Short-term Adjustments: Once a farmer decides that adjustments within the existing technical and managerial regime are necessary, what options are there? The following are some examples of adjustments possible in the middle and higher latitudes, where most of the developed countries are found.

Most scenarios of climate change indicate higher temperatures (both seasonal and annual) at middle and higher latitudes. In many areas where low temperature during the growing season is now the primary constraint on crop yield, this likely would mean increases in output. However, many of the early-maturing varieties at present grown in cool regions are not adapted to take full advantage of longer and warmer growing seasons. Consequently, substantial benefits might be gained by substituting varieties with higher thermal requirements for those now grown in those regions. This appears possible in, for example, northern Japan where the substitution of late maturing rice (at present grown in central Japan) might increase yields by 26 percent.

In the major Canadian grain growing provinces (Manitoba, Saskatchewan and Alberta) selection of different cultivars would almost eliminate crop losses that otherwise appear likely from a greenhouse warming of the kind predicted by the middle of the next century[2] In fact, in the southern prairies a switch from spring wheat, now the dominant crop, to winter wheat would avoid the stress of summer heat and dryness, thus reducing the threat of crop damage. An acceleration of the current trend from spring to winter

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2. For convenience we call this a 2 x CO_2 warming, meaning that degree of warming that would occur when CO_2 concentration reaches double its preindustrial level or when the warming effect of CO_2 and other greenhouse gases is equivalent to a doubling of atmospheric CO_2.

wheat could be an effective response to possible warmer growing seasons in the future.

Alternative patterns of fertilizer application may also be an appropriate technical adjustment to climatic changes over the long-term. Simulations based on experimental work done in Iceland indicate that fertilizer savings of up to 50 percent may be achieved in a warmer climate warmed by 2 x CO_2. Where long-term climatic changes are unfavorable it is possible that increased use of fertilizers may compensate for decreases in yield that would otherwise occur. For example, simulations based on fertilizer experiments in the USSR indicate that yields of winter rye in the Leningrad area may fall by more than a quarter under 2 x CO_2 warming, but could be increased by about 15 percent above present levels if fertilizer applications were increased by 50 percent. Whether this response would be economical would depend, of course, on fertilizer and crop prices at the time.

Changes in management strategies by Illinois corn producers in response to the GFDL and GISS scenarios[3] of climate in the U.S. midwest caused by 2 x CO_2 warming could allow corn production to continue in Illinois. The scenarios indicate that the fall season will be drier and the spring wetter in that area. The timing of many operations could be altered to adjust production to these changes. For example, more of the tillage and pre-planting activities might be done in the drier fall season offsetting the increased difficulty of getting into fields with equipment during the wetter spring. Also, earlier planting, varietal changes

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3. GFDL refers to a general circulation climate model developed by the Geophysical Fluids Dynamics Laboratory at Princeton University. GISS refers to a model developed by the Goddard Institute for Space Studies.

(discussed above) and lower planting densities (though the latter may lower yields somewhat) might help offset heat and moisture stress during warmer and possibly drier summers.

Global climate models suggest that precipitation could increase although not uniformly, in the tropics, where most of the less developed countries are located. Such a change may seem generally favorable; however, even small, localized decreases in rainfall in areas already vulnerable to drought could be quite troublesome. The experience gained by developing countries in dealing with droughts and floods provides information about measures that can help in adaptation. Jodha has prepared detailed lists of practices used in many semi-arid tropical countries as adjustments to drought. These include, for example, diversification of cropping systems, planned seasonal migration of people, shift from varieties with spreading root systems to those with deep roots and increased emphasis on crops and varieties with high salvage potential (for example, for fodder in case of a crop that fails to mature).

Long-term Adaptations: In time, the consequences of climate change are likely to exceed the capacities of farmers in developed and developing countries to adjust to them within the regime of technologies and management practices existing at that time. Policies aimed at developing new technologies and at promoting regional and national adaptations to the changed climate regime will be necessary to ease the negative impacts of the new climate on agricultural productivity. It should be emphasized that few of these policies have yet been explored in any depth. Indeed it may reasonably be argued that, at this early stage in our understanding of future climatic changes, it is more rewarding to concentrate on extending the range of policy options than on identifying and refining specific policies.

Investment in research to develop new cultivars, cultural practices and machinery, each specifically adapted to changing climate conditions, is a promising policy option. Easterling et al. cite a study by Norman Rosenberg describing the spatial expansion of hard red winter wheat in the Great Plains of the United States as an example of this promise. Between 1920 and 1980 the area of the Great Plains planted in hard red winter wheat expanded across spatial climatic gradients that exceed the climate changes expected from 2 x CO_2 warming. It was argued that the development of new cultivars and new cultural practices had allowed this expansion to occur. In a follow-on study now under way at Resources for the Future we have found that this expansion continues into southern Canada. This example suggests that agricultural technologies adapted to a variety of climatic conditions can be developed in a few decades, within the time frame expected for 2 x CO_2 warming. Similar experience exists within subsistence sectors of developing countries. Through a variety of practices aimed at diversification and flexibility, farmers in this sector have developed mechanisms to cope with climatic risks. These adaptation strategies are sources of resilience in the system and can, perhaps, offer some clues as to how adaptations can be made in the face of climatic change.

Mitigating factors

Will the development of appropriate new agricultural technologies keep pace with climate change? Can loss of comparative advantage in agriculture in a given country be averted or minimized? These are open scientific questions but their answers will be strongly dependent on factors such as the role of institutions in helping agriculture adapt and the manner in which unpriced environmental costs will be handled on farms.

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Government and nongovernment institutions will play an important role in determining the intensity of new agricultural research efforts to develop adaptations and how quickly the results are transformed into actual farm level adaptations. These institutions will also play a major role in directing the flow of resources among sectors of the economy (agriculture included) and among regions. How people in these institutions perceive climate change is crucial here. The initial condition for effective response by involved institutions is recognition that unprecedented climate change is likely and that measures will be needed to adapt agriculture to it. Jodha argues that developing countries are unlikely to achieve this recognition as soon as developed countries. Because near term development problems are so pressing in developing countries, institutions in these countries tend to respond to agricultural crises that are concrete and immediate-- drought, famine, disease. By contrast, problems of climate change are highly uncertain and relatively long term. Consequently, it should not be surprising if the developing countries take climate change less seriously than the more affluent countries do.

Agriculture, even under the best of climatic conditions, causes some damage to the environment (e.g., soil erosion, reduced water quality, reduced soil fertility, loss of wildlife habitat) and farmers in many countries already are under pressure to reduce these damages. Farm level adjustments to climate change such as, for example, the increased use of irrigation and the cultivation of marginal lands, may accelerate the loss of currently unpriced environmental values. If government policies force farmers to cover these additional environmental costs of adjustment (for example, by limiting the expansion of irrigation systems to protect instream environmental values), then real economic pressures on farmers will be increased. Moreover, if agricultural research is unable to offer

new technologies for farmers to deal with these pressures then costs of production will surely rise. Adjustments and adaptation will be made more difficult and some loss of comparative advantage may be unavoidable in regions where climate-induced environmental costs are especially high.

As this suggests, 2 x CO_2 climate change likely would improve agricultural comparative advantage for some countries, and regions, and diminish it for others. Those gaining advantage would face some problems of how to best capture the opportunities newly opening to them, but the case of the losers would be sure to excite the most concern. These countries (and regions) will face some hard choices. Three broad strategies would be open to them. One would be to accept the loss of advantage and meet needs for food security by increasing imports from the countries advantaged or unaffected by climate change. To be successful such a strategy would require policies encouraging the movement of people, land, and other resources out of agriculture and assuring them productive employment in non-agricultural sectors of the economy.

A second strategy would be to resist the climate-induced decline in comparative advantage by spurring research on development of adaptation options of the sort described above. Such a strategy would hold resources in agriculture, but it inevitably would change their mix and possibly their location within countries. To be successful, therefore, such a strategy would not only require foresight into the agricultural consequences of climate change but also policies encouraging shifts of resources into appropriate lines of research and among regions within the countries.

A third strategy open to countries losing advantage would be to protect their agriculture by restricting imports from the new advantaged countries, despite the higher economic, and possibly environmental, costs this would entail. Vested interests in agriculture likely would favor this

strategy over either of the other two, and the stronger these interests, the more likely that the strategy would be adopted. Under some conditions--say in a world of chronically and greatly increased international tension from the present level--such a strategy might also best serve the national interest in assured food security. In the absence of such tensions, however, countries losing agricultural comparative advantage would be best advised, in our judgment, to adopt one, or some combination, of the first two strategies.

Conclusions

There are a number of strategies that can be adopted to mitigate the effects of climatic changes on agriculture. The question is not "Can agriculture adapt?" but "How best can agriculture adapt?" The task over the next decade and beyond is to explore, and seek to extend, the range of options available to farmers, including favorable options to cease farming, and to evaluate the relative efficacy of these options with respect to different types and rates of climatic change. Much critical information is lacking concerning the regional detail of changes in temperature and rainfall, and in the distribution of rainfall through the year. However, it is evident that while we cannot, at present, forecast how the climate will change, we can estimate the potential consequences of each of a number of possible climatic changes. In this way we can improve our understanding of effects and explore appropriate responses. Thus as the climate changes become more apparent we shall have acquired the ability both to assess their impact and to determine the best responses.

Policy Recommendations

What policies can we recommend to help agriculture adapt to climate change? In short, a policy aimed at stimulating the creation of policy

options is a reasonable first step. Two examples of policy options to develop are: (1) the fostering of new technologies and management practices and (2) strengthening institutional mechanisms for flexible movement of land and other resources into or out of agriculture in response to climate change.

A challenge is now on the table for developed and developing country institutions to take the threat of climate change seriously and to commit research resources to the development of new agricultural technologies and management practices. Investment in research to develop new cultivars and other specifically-adapted technologies was discussed above. Similar investments to expand the range of farm management practices appropriate for changing climatic conditions also would be a promising policy option. National farm policies that aim to increase resilience to short-term climatic variability (e.g., drought, flooding, and the like) may also improve resilience to possible longer-term changes in climate. However, it may be necessary to adapt these policies specifically to encourage different types of farm management and different levels of input to match climatically-induced changes in agricultural potential. For example, further support may be necessary in traditional areas of agricultural extension work such as in water management (e.g., in improving efficiency of water use), in land management (e.g., instituting new soil management practices to improve control of soil erosion), in pest control (e.g., adopting new crop varieties and cultivation practices to inhibit pests and diseases). Continued efforts in reorganization of farm structure and rural infrastructure (such as improvements to systems of transport, marketing and credit) would be necessary, as they are today, to provide a suitable economic environment for the effective introduction of the new technologies.

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Agriculture and Forestry in a Changing Climate

Testimony of
the Natural Resources Defense Council

Before the Subcommittee on Department Operations, Research and Foreign Agriculture
and the
Subcommittee on Forests, Family Farms and Energy

Committee on Agriculture
U.S. House of Representatives

by

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TABLE OF CONTENTS

Introduction 1

Transformation of the Rural Landscape 2

Agricultural Contributions to the Greenhouse Effect 6

Some Solutions Within Agriculture and Forestry 8

Systems Research 9

Planning 11

Conservation of soil, water and prime farmland 13

Improved forest management 15

Conclusion 18

Also submitted for the record: J. Ward et al., Farming in the Greenhouse: What Global Warming Means for American Agriculture (NRDC)(1989).

Introduction

The atmospheric buildup of carbon dioxide (CO_2) and other greenhouse gases is warming the earth. If unabated, the greenhouse effect will cause an increase in average world temperature at a rate and magnitude unprecedented in human history. Positive feedbacks such as carbon releases from climate-induced forest death could cause even greater warming than that brought on by the greenhouse effect itself.

Experts are calling for prompt actions to combat the warming trend. An international collection of 300 scientists and policy leaders who convened in Toronto last summer concluded that to protect global security, "[I]t is imperative to act now."[1] Echoing the Toronto statement, the National Academy of Sciences, National Academy of Engineering and Institute of Medicine impressed the urgency of the situation upon the incoming Bush administration.[2] Early this year, Secretary of State Baker stressed the need for major reductions in greenhouse gas emissions, improved energy efficiency and reforestation to mitigate the warming trend.[3]

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[1] Environment Canada, "The Changing Atmosphere: Implications for Global Security," 1 (Conference Statement) (June 27-30, 1988).

[2] See National Academy of Sciences et al., Global Environmental Change (1988).

[3] J. Goshko, "Baker Urges Steps on Global Warming," The Washington Post (Jan. 31, 1989).

The Natural Resources Defense Council (NRDC)[4] regards global warming among the most pressing environmental challenges of our time. We strongly support major legislative initiatives such as H.R. 1078 (Schneider/Brown) and S. 324 (Wirth) that prescribe concerted actions to avert the risks of climate change.

We applaud the subcommittees' interest in the agriculture and forestry dimensions of the problem. This statement briefly examines what the warming trend may hold in store for this country's farms and forests, discusses ways that agricultural land use and management practices feed the greenhouse effect, and recommends policy adjustments for the agriculture and forestry sectors. Portions of our testimony are taken from our recent report titled Farming in the Greenhouse, which we have submitted for the record.

Transformation of the Rural Landscape

Tremendous uncertainty surrounds site-specific projections of climate change. What, for instance, will be the future

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[4] NRDC is a private nonprofit environmental protection organization founded in 1970. With principal offices in New York, N.Y., Washington, D.C., and San Francisco, NRDC has a staff of lawyers, scientists and resource specialists addressing a wide range of critical environmental problems in the United States and worldwide. NRDC is supported by more than 100,000 members.

In 1988, NRDC launched its Atmosphere Protection Initiative (API), which is a coordinated, multidisciplinary effort to address the related threats to the integrity of the earth's atmosphere -- global warming, ozone depletion, acid rain, and urban smog. Actively participating in the API are more than a dozen NRDC staff members specializing in energy conservation, forestry and agriculture, the international environment, air pollution control, coastal protection, and nuclear energy.

incidence, geographic distribution and agricultural impact of hailstorms, tornadoes and other severe weather events? This is just a sampling of factors presently beyond the predictive capability of general circulation models now used to assess future climate conditions. In a recent article in Science, noted climatologist Stephen Schneider stated that "[R]eliable prediction of the time sequence of local and regional responses of variables such as temperature and rainfall requires climate models of greater complexity and expense than are currently available."[5]

The uncertainty gives no cause for complacency or inaction. Instead, it presents a compelling need for better understanding of what to expect. In testimony delivered before Congress in 1987, Columbia University Professor of Geochemistry Wallace Broecker urged that:

> [w]hile we don't know nearly enough about the operation of the earth's climate system to make reliable predictions of the consequences of the greenhouse buildup, we do know enough to say that these impacts are potentially quite serious...To date we have dealt with this problem as if its impacts would come in the sufficiently distant future and so gradually that we could easily cope with them. While this is certainly a possibility, there is, I believe, an equally large possibility that the impacts will be considerably more dramatic.[6]

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[5] S. Schneider, "The Greenhouse Effect: Science and Policy," 243 Science 774 (Feb. 10, 1989).

[6] W. Broecker, "Greenhouse Surprises," in The Challenge of Global Warming 208 (D. Abrahamson ed. 1989).

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Professor Broecker's views are pertinent to the future of agriculture in this country and around the world. The tremendous uncertainty notwithstanding, there is a very real prospect of serious dislocation in major American farming regions. Indeed, predictions of more frequent heat waves and droughts have emerged from studies conducted at NASA's Goddard Institute for Space Studies. Last summer, Goddard Institute Director James Hansen noted "a tendency in our simulations of the late 1980s and the 1990s for greater than average warming in the Southeast and Midwest United States....These areas of high temperature are usually accompanied by below normal precipitation."[7] A further problem is that the warming trend, by some recent scientific projections, will cause greatly diminished soil moisture across much of the country, especially in the agricultural heartland.[8]

The agricultural effects of desiccated soils and hot, dry weather are not matters of conjecture. Last year, the worst drought in decades touched half the nation, cut overall crop production by one-third, caused widespread livestock losses, and exacerbated the Yellowstone forest fires. At present, Kansas and other Great Plains states are suffering severe moisture shortages

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[7] J. Hansen, "The Greenhouse Effect: Impacts on Current Global Temperature and Regional Heat Waves," in The Challenge of Global Warming, supra note 6, at 41.

[8] See S. Manabe and R. Wetherald, "Reduction in Summer Soil Wetness Induced by an Increase in Atmospheric Carbon Dioxide," 232 Science 627 (May 2, 1986).

and Dust Bowl conditions, as early indications point to a 30 percent drop in this year's winter wheat crop.[9]

Apart from the effects on managed agricultural systems, climate change could devastate forests and biotic diversity. Dr. George Woodwell, Director of the Woods Hole Research Center in Massachusetts, has cautioned that global warming could make the North American continent unsuitable for southern deciduous forests and boreal conifer forests at northern latitudes.[10] Climate change at the rate projected would likely cause the ranges of tree species to shift faster than the species can migrate.[11] Aspects of Dr. Woodwell's forecasts are reflected in the a recent EPA report to Congress, whose modelling results suggest, among other outcomes, that forests in Mississippi could virtually be replaced by grasslands and sub-tropical scrub vegetation by the middle of the next century.[12]

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[9] See S. Shellenbarger, "Unforgiving Climate of Kansas is Punishing Winter Wheat Again," The Wall Street Journal p. A-1,16 (March 14, 1989).

[10] See G. Woodwell, "Global Warming and What Can We Do About It," 8 The Amicus Journal 8-12 (Fall 1986).

[11] See L. Roberts, "How Fast Can Trees Migrate," 243 Science 735-737 (Feb. 10, 1989).

[12] U.S. EPA, The Potential Effects of Global Climate Change on the United States 11-22 (Draft Report to Congress) (Oct. 1988).

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Agricultural Contributions to the Greenhouse Effect

Agriculture is a major contributor to the greenhouse effect. In their 1988 statement, the Toronto conferees issued the following finding:

> Deforestation and bad agricultural practices are contributing to desertification and are reducing the biological storage of carbon dioxide, thereby contributing to the increase of this most important greenhouse gas. Deforestation and poor agricultural practices are also contributing additional greenhouse gases such as nitrous oxide and methane.[13]

Agriculture's role is complex, but three areas fom this summary deserve special mention.

First, land use changes within agriculture often result in release vast quantities of stored biotic carbon. In this regard, tropical deforestation and associated burning of biomass -- conducted primarily to enable expanded crop and livestock production -- accounts for approximately 10-30 percent of global CO_2 emissions.[14] Moreover, as noted by Wes Jackson, Director of The Land Institute in Kansas, conversion of prairie grasslands to annual commodity crop production results in significant net losses of stored carbon, particularly on fields prone to excessive soil erosion.

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[13] "The Changing Atmosphere: Implications for Global Security," supra note 1.

[14] Deforestation and land clearing also cause release of methane and nitrous oxide.

Second, some agricultural practices are an important source of methane, a powerful greenhouse gas currently exhibiting a one percent annual rate of increase.[15] In particular, flooded rice paddies provide ideal conditions for production of methane through the anaerobic decomposition of organic matter. Rice cultivation accounts for approximately one-fourth of the methane emissions originating from human activities.[16] Expanding herds of domestic grazing animals, especially cattle, rival rice production as an agricultural contributor to atmospheric methane concentrations.[17]

Third, inefficient application of nitrogen fertilizers results in nitrous oxide emissions to the atmosphere. A recent report from the Land Stewardship Project in Minnesota presented some findings that the efficiency of inorganic nitrogen fertilizer use (the percentage of the applied nitrogen recovered by crop plants) is only in the range of 46-58 percent, meaning that approximately half of the nitrogen is washed off of fields, leached to groundwater, or released to the atmosphere as nitrous

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[15] The one percent methane trend is attributable to a combination of sources, among them expanded rice cultivation, increased livestock production, carbon monoxide pollution of the atmosphere, and, perhaps most significant, the global warming trend itself, which accelerates methane-producing decay of organic matter from wet soils.

[16] D. Gushee et al., "Global Climate Change: The Science, Sources, Agricultural and Forestry Impacts, and Proposed Policy Responses," 10 (CRS Briefing Paper) (Nov. 21, 1988).

[17] See J. Bishop, "New Culprit is Indicted in Greenhouse Effect: Rising Methane Levels," The Wall Street Journal p. A1, 6 (Oct. 24, 1988).

oxide through the process of "denitrification."[18] In addition to feeding the greenhouse effect, inefficient use of applied nitrogen amounts to wasteful consumption of, and greenhouse emissions from, natural gas and other fossil fuels used as feedstocks in the manufacture of fertilizer products.

Some Solutions Within Agriculture and Forestry

The Washington Post recently urged that the United States assert leadership in the international fight against global warming. The paper's editors observed that "[i]t is entirely correct to say that no country can, by itself, protect the planet's atmosphere. But it is also true that environmental protection, like charity, begins at home."[19]

This bit of insight pertains directly to the needed assault on greenhouse gas emissions through energy conservation, development of renewable energy sources, a rapid phase out of chlorofluorocarbons, and an end to tropical deforestation. The notion of environmental diplomacy is highly relevant to the agriculture and forestry issues raised by this hearing. The following are steps that Congress, USDA, and the American farming and forestry communities should undertake as part of a comprehensive global solution.

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[18] See D. Granatstein, Reshaping the Bottom Line: On-farm Strategies for a Sustainable Agriculture 13-16 (Land Stewardship Project) (1988).

[19] "Environmental Diplomacy," The Washington Post p. A18 (March 28, 1989).

Systems research. In and of itself, more basic research is no substitute for prompt, concerted actions to mitigate the greenhouse effect. Nevertheless, improved scientific understanding will enable us better to combat, plan for, and cope with warmer conditions.

Unfortunately, most of the climate change research conducted by USDA, largely with financial support from the Department of Energy, is focused on the narrow issue of crop growth enhancement in CO_2-enriched atmospheres. Bold predictions from USDA researchers of dramatic crop yield increases have become regular features in major farm magazines.[20] The principal message being conveyed by the government scientists is that the warming trend will not present serious problems for the nation's farmers and, in fact, may prove a tremendous boon to American agriculture.

As noted in our Farming in the Greenhouse report, it is hazardous to extrapolate from the experimental findings concerning CO_2 "fertilization" to circumstances in the real world. Although biotic carbon fixation is a matter of considerable scientific interest, it should not be a centerpiece of the federal research program concerning climate change. The current USDA research direction tends to foster an unfounded complacency over the greenhouse gas buildup, and may even point

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[20] See, e.g., L. Palmer, "Farming Under the 'Greenhouse Effect,'" 113 Farm Journal 14 (Jan. 1988); J. Bahls, "The Good Greenhouse Effect?" 17 Farm Futures 10 (Mar. 1989).

to the perverse conclusion that increased atmospheric emissions of CO_2 are desirable.

Our report recommends that the Department shift toward a research program that examines the full range of interactions between climate change and agricultural and forest systems. The highest priority should be to develop ways of reducing greenhouse gas emissions from agricultural sources. For example, adjusutments in dietary patterns that enable reduced beef production hold significant promise for abatement of methane production and reduced deforestation. Of equivalent importance, the USDA program should be geared -- through such efforts as development of alternative crop varieties and protection of biotic diversity -- toward protecting American agriculture in the face of whatever climate change may now be irreversible.

Among the pieces of global warming legislation now pending, Title VIII of H.R. 1078 reflects an intelligent, systems-based approach to research in agriculture and forestry. Among other beneficial features, that bill would authorize an intergovernmental analysis of linkages between agricultural production and global climate change, as well as expanded research projects under the Agricultural Productivity Act designed to increase fixation of nitrogen and carbon on farms and to enable farmers to reduce their reliance on fossil fuel inputs.

We are somewhat encouraged by recent research initiatives at USDA. In particular, the Forest Service has assigned a high priority to research focused on the condition of forest

ecosystems under global warming.[21] A new draft description of USDA's overall strategy for research on global climate change suggests that the Department at large is beginning to adopt a broader program. Congress should exercise vigorous oversight to ensure that systems research takes the place of what has been a misplaced, one-dimensional emphasis on projected benefits of rising CO_2 concentrations.

Planning. Rational planning is a badly needed alternative to blind faith in the adaptive capability of this nation's agricultural and forest systems. Contrary to the assertions of some USDA researchers that adjustments forced by global warming will not present much of a problem for American farmers, adaptation will be seriously constrained by such factors as poor soils at northern latitudes, declining irrigation water supplies, and limits on plant breeding technology.

We share the view of William Moomaw, Director of the World Resources Institute's (WRI) Climate Program, that USDA "should prepare a long-range plan for adapting U.S. agricultural and forestry policies to the potential consequences of climate change."[22] Mr. Moomaw urges that such a plan must include

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[21] USDA Forest Service, Forest Health and Productivity in a Changing Atmospheric Environment: A Priority Research Program (Forest Fire and Atmospheric Sciences Research Staff) (1989).

[22] W. Moomaw, "Near-term Congressional Options for Responding to Global Climate Change," in The Challenge of Global Warming, supra note 6, at 320.

consideration of possible shifts in production zones and preparation for a large increase in forest fires. To this we would add the need for more systematic drought planning at the federal level, a sensible recommendation advanced by Don Wilhite from the University of Nebraska's International Drought Information Center.

Improvements are needed in various planning functions currently administered by USDA. In particular, climate change should be factored fully into the Resources Planning Act (RPA) process conduced by the Forest Service. The agency's latest RPA "Analysis of the Timber Situation" projected timber conditions nationally over the next half century without meaningful consideration of potential impacts from climate change.[23] In view of the mounting scientific concern over global warming's impacts on forests, this approach is at best naive and at worst a prelude to bad forest management choices in the short run.

Climate change should likewise be integral to the soil and water assessments and programs developed by USDA's Soil Conservation Service under the Resources Conservation Act (RCA). The Department has never considered the planetary warming trend within RCA, and has thus formulated questionable judgments on the adequacy of natural resources for future food supplies and protection of the rural environment.

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[23] See Letter from The Hon. Patrick Leahy to USDA Secretary Lyng and Forest Service Chief Robertson (Dec. 27, 1988).

Conservation of soil, water and prime farmland. To avoid exacerbating problems that may arise from climate change, we should conduct careful stewardship of those finite natural resources basic to sustained agricultural production. Thus, with respect to cropland soils, USDA should strengthen implementation of the 1985 Food Security Act's conservation compliance provision. Under current rules and policies, SCS is routinely developing "alternative conservation systems" that, per se, fail to prevent productivity-threatening rates of soil erosion.[24] This has potentially large implications for long-term food security, as the conservation compliance provision seeks to maintain or initiate effective erosion control on some 118 million acres of highly erodible land constituting more than one-fourth of the national cropland base.

Water conservation is also essential to preparing for life in a warmer world. In this regard, we concur with Melvin Cotner, a former deputy administrator of USDA's Economic Research Service, who recommends an end to federal subsidies for new irrigation development that drives needless over-production of surplus crops.[25] In addition, the federal government should end

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[24] See generally, The Soil Conservation Service's Implementation of the Soil Conservation Provisions of the Food Security Act of 1985: Hearing before the Subcomm. on Nutrition and Investigations of the Senate Comm. on Agriculture, Nutrition and Forestry, 100th Cong., 2d Sess. (1988).

[25] M. Cotner, "Waterbusting: Irrigation Aggravates Commodity Surpluses," 42 Journal of Soil and Water Conservation 335-338 (Sept.-Oct. 1987).

water price subsidies for producers in the western states served by Bureau of Reclamation projects.[26]

Finally, to help preserve food production options in a warmer world, the Department of Agriculture must fulfill its duties under the Farmland Protection Policy Act (FPPA). Enacted in 1981, the FPPA's leading purpose is to limit the federal government's sizable contribution to the permanent loss of those farmlands best suited to long term agricultural production. Throughout this decade, the USDA record on this issue has been nothing short of dismal, as each year hundreds of thousands of acres of prime farmland continue to give way -- often with taxpayer assistance -- to highways, shopping malls, subdivisions and other developments.

As a first step toward curing this problem, Congress should force promulgation of a farmland protection rule proposed by USDA in early 1987.[27] That rule would implement strengthening amendments enacted as part of the 1985 Food Security Act and, among other things, reverse the misplaced provision in the existing FPPA rule that prohibits denial of federal assistance when developers have not bothered to conduct a proper search for alternatives to converting prime farmland.

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[26] See E. LeVeen and L. King, Turning off the Tap on Federal Water Subsidies (NRDC and California Rural Legal Assistance Foundation) (Aug. 1985).

[27] USDA, Revision of Farmland Protection Policy Act, 52 Fed. Reg. 1465 (proposed Jan. 14, 1987).

Improved forest management. Sound forestry must be an important ingredient in any comprehensive solution to the greenhouse effect. On this score, there are several areas in which the United States should take the lead.

First, we should seek greatly expanded establishment of carbon-storing forest cover under the conservation reserve program. The many advantages of such an initiative are set forth in our Farming in the Greenhouse report. It is important to note that establishment of new forests does not foreclose, but rather protects, long-term options for food production. As Lauren Soth, a former editorial page editor for The Des Moines Register has observed, planting trees:

> does not remove for all time the use of hill land for corn and wheat. It merely pulls back from current overuse of the land which has come about as a result of new farm technology, reckless lack of planning and pressure from agribusiness to increase output of basic raw materials.[28]

Second, in order to assert credible leadership in forest management, the U.S. Forest Service must provide a better model for other nations. It is difficult for the United States effectively to promote forest conservation in the Amazon Basin, for example, while we continue to permit widespread destruction of our own rainforests in the Pacific Northwest and Alaska.

Significantly, the remaining old growth forests of the Pacific Northwest store more carbon than any other ecosystem on

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[28] L. Soth, "Trees for Life, and Better Farm Policy," The Des Moines Register p. 10A (Oct. 10, 1988).

earth, provides many times the comparable carbon storage of tropical rainforests.[29] In fact, the amount of carbon released from logging an acre of old growth -- through slash burning and the rapid decomposition of leaves, bark and roots following removal of merchantable trees -- is greater that the total carbon stored in an acre of Amazon rainforest.[30] Even where young timber plantations with high rates of CO_2 absorption are successfully established in the aftermath of old growth clearcutting, well more than a century is required to replenish the carbon released in the initial logging operation.[31]

Compounding its poor performance on protection of old growth and biotic diversity, the Forest Service is falling short in its obligation to ensure reforestation of cutover federal lands. According to a recent report from The Wilderness Society, long range management plans being developed for the national forests are prescribing intensive timber production on physically sensitive lands where prompt reforestation is difficult or

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[29] See R. Waring and J. Franklin, "Evergreen Coniferous Forests of the Pacific Northwest," 204 Science 1382 (June 29, 1979); S. Brown and A. Lugo, "Biomass of Tropical Forests: A New Estimate Based on Forest Volumes," 223 Science 1291 (Mar. 23, 1984).

[30] Recent research on U.S. forests has shown that, on average, only approximately one-third of the total forest biomass is in the form of merchantable wood. See W. Johnson and D. Sharpe, "The Ratio of Total to Merchantable Biomass and its Application to the Global Carbon Budget," 13 Canadian Journal of Forest Research 372-383 (1983).

[31] The carbon storage of a 100-year old Douglas-fir forest is still only half that of an old-growth forest. See R. Waring and J. Franklin, supra note 29.

impossible.[32] This is unfortunately the case despite reforms in the 1976 National Forest Management Act intended to cure this problem.

There is likewise substantial room for improvement in reforestation efforts on this nation's private timberlands. According to USDA estimates, for example, only approximately 60 percent of harvested nonindustrial pine lands in the South now undergo reforestation.[33] Although this signals progress from a decade ago -- when the comparable figure was just 46 percent -- the current situation remains unacceptable.

Concerning nonindustrial private forest (NIPF) management, there may be significant potential for mitigating CO_2 emissions through more intensive, sustained yield timber production on these lands, which now contribute a disproportionately small share of the nation's wood supply. Forest Service data suggest that annual timber growth on NIPF lands could be increased by 3.7 billion cubic feet, enough to satisfy more than half the increase in demand for wood the Forest Service has projected for 2020.[34]

Tapping this opportunity could provide a valuable new biotic carbon sink while relieving logging pressures on the national

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[32] H. Carey et al., Reforestation Programs and Timberland Suitability (The Wilderness Society)(Sept. 1988).

[33] G. Dunlap, "The South's Fourth Forest: Opportunities to Increase the Real Wealth of the South and the Nation," 47 Forest Farmer 12 (July-Aug. 1988).

[34] USDA Forest Service, Draft Analysis of the Timber Situation in the United States 1989-2040 9-25, 7-27 (1988).

forests. We therefore have recommended increased federal support through a mixture of tax benefits and direct financial and technical assistance to encourage more intensive and more environmentally protective NIPF management.[35]

Finally, we favor greatly expanded tree planting in urban areas. By virtue of furnishing shade, urban trees reduce energy requirements for cooling buildings and thus provide a greenhouse abatement benefit 15-20 times greater than that provided by biotic carbon absorption alone. American Forestry Association figures derived from studies conducted at the Lawrence Berkeley Laboratory in California indicate that a campaign to plant 100 million trees in cities nationwide could mitigate some 18 million tons of carbon emissions each year. Such an effort deserves strong backing from all levels of government, as well as the private sector.

Conclusion

There is no doubt that global climate change will profoundly affect agricultural and forest systems. The exact timing and location of impacts is largely a matter of speculation, but it is not productive to rest on the assumption that we will be able successfully to confront whatever changes come about. American agriculture and forestry have displayed tremendous resilience

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[35] F. Kaid Benfield et al., Taxing the Tree Farm: Sensible Policies for Sensible Private Forestry (NRDC)(May 1988).

over the decades, but the global warming trend by all accounts will bring unprecedented challenges.

The recommendations in this testimony are far from a complete solution to the greenhouse effect. They are, nevertheless, sensible steps that should be undertaken even for reasons wholly apart from climate change. Collectively, our proposals would help improve the United States' posture as an environmental emissary, mitigate significant amounts of greenhouse gas emissions, and help prevent environmental and socio-economic dislocation.

CLIMATE CHANGE AND U.S. AGRICULTURE

STATEMENT OF

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Introduction

Mr. Chairman, members of the Committee, as coordinator of the agricultural studies done for the U.S. Environmental Protection Agency's Report to Congress on The Potential Effects of Global Climate Change on the United States, I would like to share with you the findings and relevant implications of the results.

The studies completed for the EPA report are a first step in linking models of climate change to models of agricultural impacts. They were designed to help define the potential scale of climate change impacts on U.S. agriculture. While the studies represent the most comprehensive analysis, to date, of these potential impacts, the findings are initial projections of the sensitivity of American agriculture to the estimated climatic changes, rather than predictions of what will occur. The EPA report is currently in draft form and undergoing scientific and interagency review.

Given global climate change, the main conclusions that may be drawn from the EPA studies are: (1) U.S. food supply appears to be sufficient to meet domestic needs, but export levels could decrease, (2) significant regional shifts in agricultural production are likely, (3) demand for water for irrigation is estimated to rise in many regions of the country, and (4) the extent to which the direct effects of CO_2 will be beneficial is uncertain.

Climate and agriculture

Before providing the details of the EPA analysis, it is important to note that climate and weather have been and continue to be dominant factors in agricultural productivity, despite technological advances such as improved hybrids and the widespread use of chemical fertilizer. We have only to compare the Dust Bowl years of the 1930s when wheat and corn yields dropped by up to 50% and the summer of 1988 when the nation's corn crop decreased by almost 40% to see that American agriculture is still vulnerable to extreme climatic events.

Atmospheric scientists are now projecting temperature increases by early in the next century to levels higher than any in at least the past 150,000 years. Associated alterations in rainfall and soil moisture are also expected, but these predictions are less well defined. Although the climate projections are uncertain, especially in regard to the rate of change and regional specificity, their magnitude creates the need for a broad consideration of the impacts of potential climate change on U.S. agriculture.

Recognizing this need, Congress sent a formal request to the

EPA Administrator in 1986 to undertake a study of the potential health and environmental effects of climate change, including the potential impacts on agriculture.

Structure and rationale of the EPA agricultural studies

In order to carry out the Congressional request, EPA developed a set of climate change scenarios based on global climate model output for doubled levels of atmospheric CO_2. EPA selected the results of several different climate models in order to explore a broad range of future climates. These scenarios were used in models of agricultural systems to determine the potential effects of climate change. The studies involved the following research areas, either regionally or nationally: 1) crop growth and yield; 2) regional and national agricultural economics; 3) demand for irrigation water; 4) water quality; 5) pest-plant interactions; 6) direct effects of CO_2 on crop growth and yield; 7) impacts of extreme events; 8) potential farm-level adjustments; 9) livestock pests and diseases; and 10) agricultural policy. (See attached list of projects.)

Among the key questions in estimating the agricultural impacts of climate change are: Will the U.S. be able to produce enough food to feed its population in the future? What changes will occur on a regional and local level? and Will farmers be able to adapt? The EPA studies sought to answer these questions.

Another critical issue is the role of CO_2 itself. Besides acting as a greenhouse gas and warming the atmosphere, increased levels of CO_2 also increase crop growth and improve water use in plants. There are major differences of opinion in the research community about the extent to which the beneficial effects of increasing CO_2 will mitigate negative climate change effects on agriculture. What will the magnitude of the positive effects be in relation to the predicted climate changes? Will the direct effects mitigate or overcome the climate effects? Several modeling studies undertaken for the EPA report addressed this issue; they examined both direct physiological effects and climatic effects of carbon dioxide simultaneously.

Simulated regional changes in crop yields and hydrology were then used in a national agricultural economics model to estimate regional and national changes in crop production, land use, and demand for irrigation. Such a coordinated analytical framework is necessary in order to account for the effects of market forces on the total agricultural system, including livestock, and to evaluate the adequacy of the nation's resource base for agricultural production.

Uncertainties

The sources of uncertainty are many. The climate scenarios

did not include changes in interannual variability, such as changes in the frequencies of drought or storms, even though these could affect crop yields significantly. The climate models have not yet been validated to project these types of changes. The effects of changes in levels of tropospheric and stratospheric ozone on crops were not considered, nor were changes in levels of pest infestations. The crop models, while among the best now available for large-area studies, are simplistic, and may not provide correct estimates for the extreme climatic conditions created by the climate change scenarios. The crop models can only approximate the physiological effects of CO_2 on crop growth and water use at this time. Finally, the range of possible alternative cropping strategies was not fully explored in the studies, such as substitution of different crop species, nor were potential changes in foreign demand for U.S. agricultural commodities.

Now, let me review the conclusions in further detail.

Findings and implications

1. U.S. food supply appears to be sufficient to meet domestic needs, but export levels could decrease.

The EPA studies imply that the projected climate change does not threaten food supply for the nation, even under more extreme climate scenarios. Production capacity of U.S. agriculture appears to be adequate to meet domestic needs. However, if droughts occur more frequently under changed climate, effects on agriculture may be more severe.

Model projections done for the EPA report show that U.S. exports may decline significantly, based on a study in which the demand for exports did not change. It is important to note that climate change may expand or limit agricultural production in other areas of the world, and that changes in U.S. agriculture will take place in this global context. The overall result could be changes in the patterns of global food trade, in particular the demand for U.S. exports.

We also examined the effects of improvements in productivity caused by future technology and the impact of increased population demand for food, along with climate change. In this situation, continued advances in U.S. agricultural technology equal to those that have occurred over recent decades would be necessary to offset the negative effects of climate warming. Another way of saying this is that improvements in production are likely to be small despite new technologies if climate change occurs. This suggests the need to maintain a strong agricultural research program in the United States.

2. Significant regional shifts in agricultural production are likely.

If the current understanding of global climate warming is qualitatively correct, agricultural land in more southern latitudes may go out of production, while agricultural acreage is likely to expand in the north, as shown in Fig. 1. All climate change scenarios tested show that the southern areas of the United States become less productive relative to northern areas. This is primarily because the high temperatures predicted for climate change will stress crop production more in southern areas than in northern areas where crops are currently limited by lower temperatures and shorter growing seasons. The lack of fertile agricultural soils in northern areas may limit this expansion. Fig. 2 shows modeled soybean yield changes for climate change scenarios with and without the direct effects of CO_2 at selected locations.

Other potential changes likely to occur include changes in infestations of crop pests, altered ranges of livestock pests and diseases, and higher levels of heat stress on livestock. For example, a northward extension of crop pest ranges and increased pest populations may reduce yields and affect livestock (see Fig. 3). Warmer temperatures may result in northward extension of the range of diseases and pests that now afflict livestock in the south, and could make conditions more favorable for introduction of new livestock diseases into the southern United States. These effects are all driven in large part by high temperatures.

As climate changes, farmers are likely to adapt with alterations in management practices, such as earlier planting dates, crop types and varieties appropriate to the new climatic regimes, and development of irrigation systems. If climate change is not severe, these adjustments may mitigate losses in crop yields. More severe climate change is likely to make adaptations more difficult and more costly, with increased likelihood that farms would be abandoned.

Regional changes in agriculture have important implications for rural communities. The industry of agriculture is composed of many people besides farmers, such as, farm equipment manufacturers, fertilizer and seed suppliers, and rural bankers, to name but a few. As production areas shift, climate change effects will reverberate through this larger community and are likely to result in structural changes in local economies such as relocation of markets and transportation networks. At its most extreme, climate change could cause dislocation of rural communities through farm abandonment.

Natural environments may also suffer because of these changes in agriculture due to greater need for pesticides, the potential for increased soil erosion, and loss of wildlife

habitats. Shifts in regional production patterns imply changes in ground and surface water pollution, and chemical pesticide usage may change to control both crop and livestock pests. Thus, climate change could exacerbate many of the current trends in environmental pollution and could initiate new ones.

3. Demand for water for irrigation may rise.

Demand for water for irrigation is likely to rise with warmer temperatures. Fig. 4 shows that irrigated acreage is projected to rise with climate change. Increased demand for irrigation occurs for a number of reasons. First, crops need more water when grown in higher temperatures. Second, farmers are likely to respond by irrigating in order to ensure stable yields under hotter, drier conditions. Third, higher crop prices (caused by the inelastic demand for agricultural commodities) would make the costs of irrigation feasible for more farmers. Peak demands for irrigation systems are also likely to rise with climate change, indicating the potential need for greater irrigation capacity.

Rising demand for irrigation water could place additional stresses on water systems already being overdrawn, such as the Ogallala Aquifer in the Great Plains. Also at potential risk is the quality of surface and groundwater as depletion of water from these sources increases concentrations of pollutants.

These studies did not consider changes in competing demands for water, which may be altered in a warmer climate. Costs of developing irrigation systems in new locations and increasing capacity in currently irrigated areas may be high, and actual implementation of expanded irrigation systems depends on the economics of each local situation.

4. The extent to which the direct effects of CO_2 may be beneficial is uncertain.

Regional changes in U.S. agriculture are predicted even when beneficial physiological effects of increased carbon dioxide on crop growth are taken into account. While the beneficial effects of CO_2 may mitigate or actually overcome negative climate effects on yields in some areas, agricultural productivity shifts occur in any case. Thus, an optimistic estimation of yield increases caused by higher levels of CO_2 does not preclude significant changes in regional agriculture in the future. This result is illustrated in Fig. 1 where changes in regional agricultural acreage are simulated both with and without the physiological effects of CO_2 on crop yields.

Furthermore, few experimental studies have examined the interactive effects of CO_2, water, nutrients, light, and

temperature on crop growth and development. Interactive studies are needed to accurately predict the combined effects of all these future stresses on crop yields. Thus, uncertainty exists concerning the extent to which the beneficial effects of increasing CO_2 will be seen in crops growing in variable, windy, and pest-infected (weeds, insects, and diseases) fields under climate change conditions.

Research and policy

The results of the EPA studies indicate a need for continued analyses and research. As mentioned earlier, a strong research effort must be maintained in order to ensure technological improvements in agriculture and limit vulnerability to climate change, including continued development of crops which are drought and heat tolerant, and species acclimated to the projected changed climate regimes. Additional analyses of the impacts of climate change scenarios on major crops will be important, as well as study of the potential effects on specialty crops and other agricultural sectors such as the dairy industry. One of the most crucial areas for further research is the projection of potential climate change effects at the international level, and the implications of the projected shifts in global agriculture for U.S. trade. Therefore, a study of international effects of climate change should be undertaken. These efforts must be accompanied by continued improvement in our ability to estimate regional climate changes.

It is also appropriate to examine current agricultural policies, such as the U.S. commodity programs, in light of the need for flexibility in adjusting to potential future warming. Do these and other farm policies encourage farmers to adapt as easily as possible to changing climatic conditions? Of course, given the large uncertainties about climate change, policies designed to help U.S. agriculture prepare should also make sense for today. For example, drought planning could be improved, thereby helping today's farmers and also providing insurance against potential future droughts. Other policies to examine in the light of climate change are land-use and water-resource management and water quality regulations. Finally, the implications of potential long-term changes in the levels of U.S. crop exports for the U.S. balance of trade should be considered by relevant policymakers.

Conclusions

While many critical uncertainties remain about the magnitude and timing of impacts, it appears that climate change is likely to affect agriculture and rural communities in the United States significantly in the coming century. If the higher temperatures that are predicted by global climate models occur, changes in

regional crop yields, crop irrigation requirements, heat stress on livestock, and infestation of agricultural pests and diseases, may ensue. Farmers can make some adjustments to less severe climate change by planting earlier, substituting better-adapted crop varieties and species, and increasing demand for water for irrigation. More severe climate change will likely require major adaptations, including expansion of irrigation infrastructure, farm abandonment and rural dislocation, in some regions.

The initial analysis of climate change impacts on U.S. agriculture provided by the EPA studies indicates that comparative advantage among farming enterprises and regions and hence patterns of agriculture are likely to shift within the United States. While, on a national scale, the domestic supply of agricultural commodities should be sufficient (if drought frequency does not increase), concern for our major resources (especially land and water), rural communities, and the environment appears justified. The impacts of climate change on agriculture in its larger role as a renewable resource base that provides industrial and domestic products beyond food and fiber also need to be considered. Furthermore, the need to consider climate change effects in a global context, particularly in relation to the role of the United States as a reliable supplier of agricultural export commodities, becomes a necessity.

Agriculture Projects for EPA Report to Congress on
The Potential Effects of Global Climate Change on the United States

Regional Studies

- Effects of Projected CO_2-Induced Climatic Changes on Irrigation Water Requirements in the Great Plains States -- Allen and Gichuki, Utah State University
- Climate Change Impacts upon Agriculture and Resources: A Case Study of California -- Dudek, Environmental Defense Fund
- Farm-Level Adjustments by Illinois Corn Producers to Climatic Change -- Easterling, Resources For the Future
- Impacts of Climatic Change on the Fate of Agricultural Chemists Across the USA Great Plains and Central Prairie -- Johnson, Cooter, and Sladewski, University of Oklahoma
- Impact of Climate Change on Crop Yield in the Southeastern USA: A Simulation Study -- Peart, Jones, Curry, Boote, and Allen, University of Florida
- Effects of Global Climate Change on Agriculture: Great Lakes Region -- Ritchie, Baer, and Chou, Michigan State University
- Potential Effects of Climate Change on Agricultural Production in the Great Plains: A Simulation Study -- Rosenzweig, Columbia University

National Studies

- The Economic Effects of Climate Change on U.S. Agriculture: A Preliminary Assessment -- Adams, Glyer, and McCarl, Oregon State University
- Analysis of Climate Variability in General Circulation Models -- Mearns, Schneider, Thompson, and McDaniel, National Center for Atmospheric Research
- Direct Effects of Increasing CO_2 on Plants and Their Interactions with Indirect (Climatic) Effects -- Rose
- Potential Effects of Climatic Change on Plant-Pest Interactions -- Stinner, Rodenhouse, Taylor, Hammond, Purrington, McCartney, and Barrett, Ohio Agricultural Research and Development Center
- Agricultural Policies for Climate Changes Induced by Greenhouse Gases -- Schuh, University of Minnesota
- Changing Animal Disease Patterns Induced by the Greenhouse Effect -- Stem, Mertz, Stryker, and Huppi, Tufts University
- Effect of Climatic Warming on Populations of the Horn Fly -- Schmidtmann and Miller, USDA Agricultural Research Service

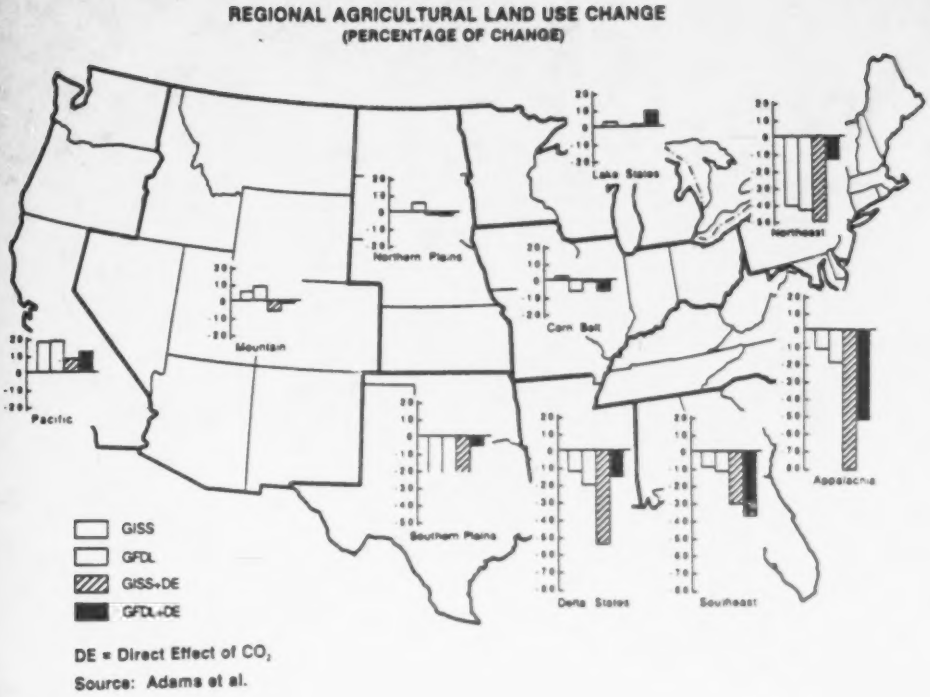

Figure 1. Percent change in regional agricultural acreage simulated by an economic model of the U.S. agricultural sector for the GISS and GFDL climate change scenarios with and without the direct effects of CO_2 on crop yields.

Source: Adams et al.

Figure 2. Percent change in rainfed soybean yields simulated by the SOYGRO model for baseline (1951-1980) and GISS and GFDL climate change scenarios with and without the direct effects of CO_2 for selected locations.

Source: Peart et al.; Ritchie et al.

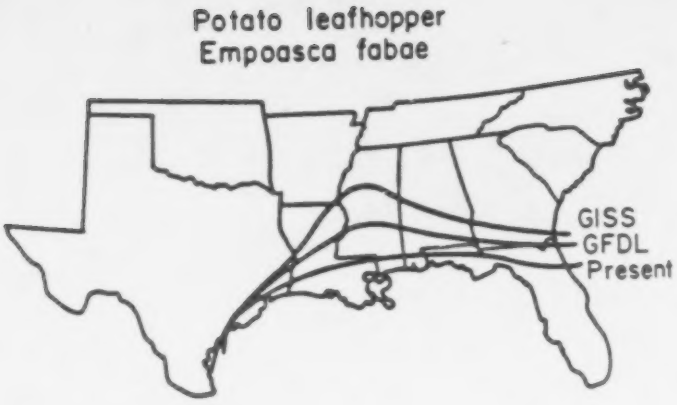

Figure 3. Present and potential (GISS and GFDL climate change scenarios) overwintering range of the potato leafhopper, Empoasca fabae, a major pest of soybeans.

Source: Stinner et al.

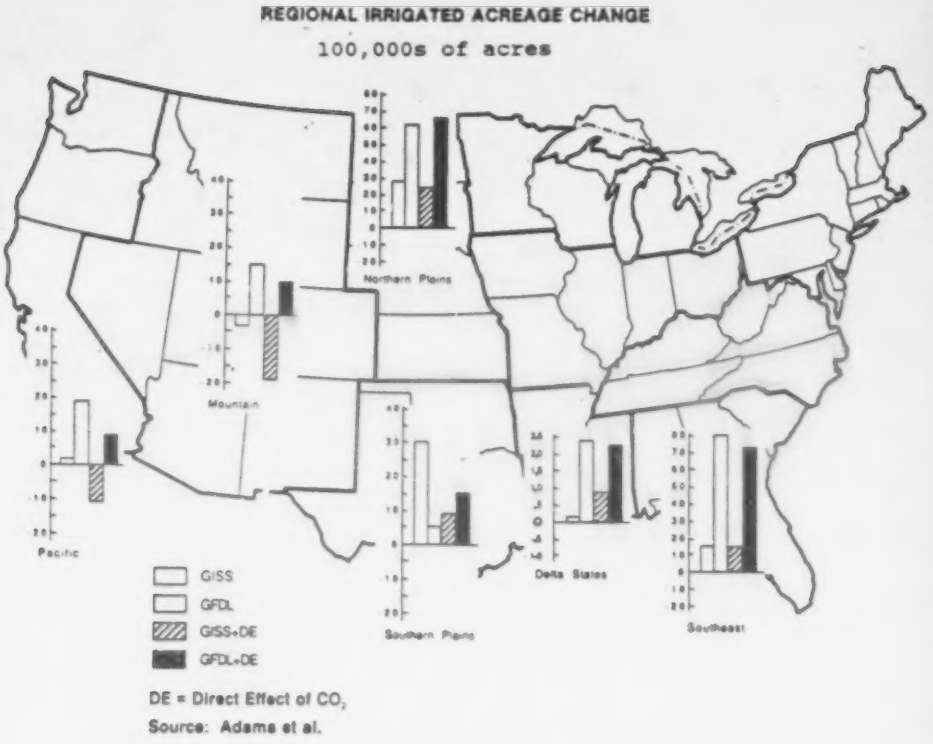

Figure 4. Change (100,000s of acres) in regional irrigation acreage simulated by an economic model of the U.S. agricultural sector for the GISS and GFDL climate change scenarios with and without the direct effects of CO_2 on crop yields.

Source: Adams et al.